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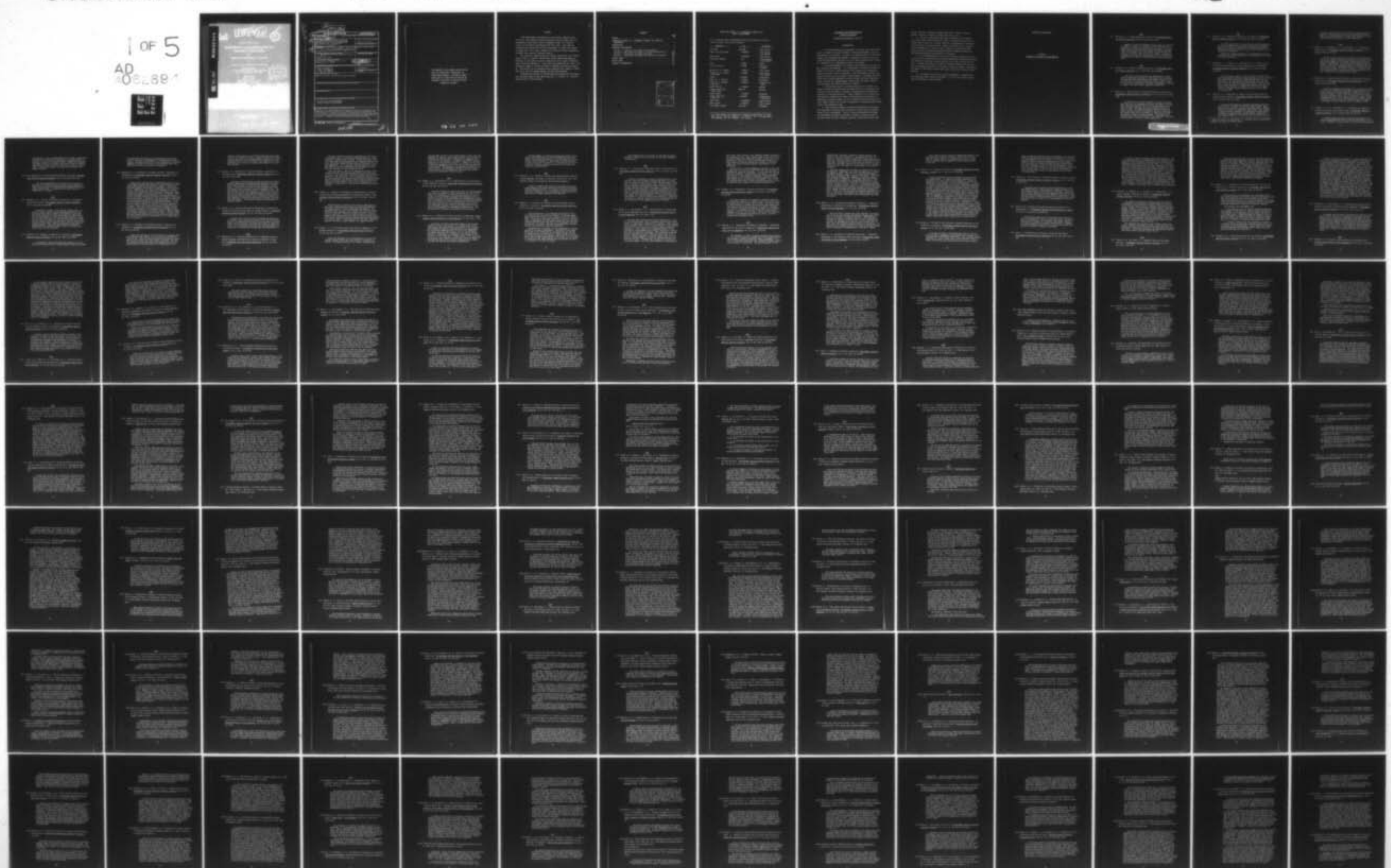

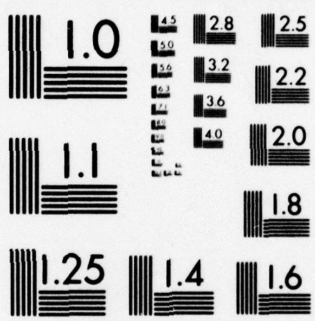

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MAINTENANCE AND PRESERVATION OF CONCRETE STRUCTURES

Report 1

ANNOTATED BIBLIOGRAPHY, 1927-1977

by

Tony C. Liu, Edward F. O'Neil, James E. McDonald

Concrete Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Included in this bibliography are 826 annotated references on maintenance and preservation of concrete structures. They cover the period from 1927 to 1977 on the subjects of durability and causes of deterioration, evaluating the condition of existing structures, maintenance and repair materials, procedures, and techniques. A complete subject index and author index are provided.

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PREFACE

This bibliography was prepared at the Concrete Laboratory (CL) of the U.S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Office, Chief of Engineers (OCE), U.S. Army, as a part of Civil Works Investigation Work Unit 31553. The study was authorized 16 February 1977 by first indorsement of a WES letter dated 3 January 1977. Mr. James A. Rhodes of the Concrete Branch, Engineering Division, OCE, served as technical monitor.

The study was conducted under the general supervision of Mr. Bryant Mather, Chief, CL, and Mr. John Scanlon, Chief, Engineering Mechanics Division, CL, and under the direct supervision of Mr. James E. McDonald, Chief, Structures Branch, CL. This report was prepared by Dr. Tony C. Liu and Messrs. Edward F. O'Neil and James E. McDonald of Structures Branch, CL. The majority of the references were compiled by Mr. Edward F. O'Neil, SP5 John Z. Oak, Mr. Andrew Lindsey, and Ms. Tracy Flanagan.

Commander and Director of the WES during this study and the preparation and publication of this report was COL J. L. Cannon, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acre-feet	1233.489	cubic metres
cubic feet per second	2.831685	cubic metres per second
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	3.785412	cubic metres
gallons (U. S. liquid) per minute	0.00006	cubic metres per second
inches	25.40000	millimetres
miles (U. S. statute)	1.609344	kilometres
miles (U. S. statute) per hour	1.609344	kilometres per hour
pounds (force)	4.448222	newtons
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square yards	0.8361274	square metres
tons (2000 lb mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

MAINTENANCE AND PRESERVATION OF CONCRETE STRUCTURES

ANNOTATED BIBLIOGRAPHY, 1927-1977

INTRODUCTION

1. The deterioration and maintenance of concrete civil works structures is a common and serious problem, involving considerable cost and inconvenience to the public. As part of a concerted effort to solve this problem, this annotated bibliography is prepared for those who are concerned with maintenance and repair of civil works structures and to serve as a framework for a comprehensive study on the subject.

2. An understanding of the causes of deterioration is, by far, the most difficult and important. It is impossible to evaluate the need for repair or to select a repair procedure with assurance of satisfactory results unless the cause is understood. This bibliography collects 218 papers in section A on the causes of deterioration. The papers deal with topics such as alkali-aggregate reaction, sulfate and other chemical attacks, freezing and thawing damage, reinforcement corrosion, abrasion and cavitation, and biodeterioration of concrete.

3. Knowing the cause of a problem being the first concern, the degree to which the deterioration has taken place is of importance, and section B notes 147 papers on methods of determining the strength and condition of existing structures. Primary emphasis in this section has been placed on nondestructive means of determining such properties as compressive strength, dynamic and static modulus, density, moisture content, cement content, air content, and methods of locating internal voids, cracks, and delaminated areas.

4. With cause and degree of deterioration understood, materials and techniques of applying these materials to affect the best possible repair can be investigated. Section C deals with materials available for maintenance and repairs and gives 179 papers on materials such as portland cement concrete, asphaltic mixtures, epoxy-resin concrete and

mortar, shotcrete, drypack, portland cement grout, fibrous concrete, polymer concrete, protective coatings, and joint sealers.

5. Section D, maintenance and repair procedures and techniques, lists papers that discuss methods of repair, maintenance practices, procedures used to make use of repair materials, strengthening of structures, and evaluation of repair materials. Repair techniques such as overlays, steel strengthening of concrete, fiber reinforced and epoxy patching, prepakt concrete, pressure grouting and epoxies, membrane applications, and bonding techniques are presented in 282 papers.

6. In the bibliography, each entry of literature appears only once in the section in which the title is most significantly identified, although the contents of some may be associated with two or more sections of subjects. Attempts were made to include all relevant references in the subject of maintenance and repair of concrete structures; however, considering the number of references in this broad field, many articles may have been omitted.

7. As a guide for the users of this bibliography, a complete subject index and author index are provided. A list of the sources containing the references is also included.

ANNOTATED BIBLIOGRAPHY

SECTION A

DURABILITY AND CAUSE OF DETERIORATION

1929

A-1 Williams, G. M., "Disintegration of Concrete," Proceedings, American Concrete Institute, Vol 26, Nov 1929, pp 41-56.

Summary of available knowledge of the nature of corrosion as found in concrete - its causes, effects, and control in manufacture, curing, and insulation of protection. The most common forms of deterioration encountered may be classified under the headings of (1) acid action, (2) weathering, (3) action of sea water, and (4) action of alkali. Information is given on the reactions taking place in each case and recommendations are made for the prevention of such disintegration.

1931

A-2 McMillan, F. R., "Study of Defective Concrete," Proceedings, American Concrete Institute, Vol 27, May 1931, pp 1039-1090.

A survey of concrete structures representative of many types of aggregates, methods of construction and conditions of exposure in the United States and Canada. Types of defective concrete are illustrated and the causes traced to such factors as mix, consistency, soundness of aggregates, quantity of cement, and other faulty construction practices.

A-3 Young, R. B., "More Lessons from Concrete Structures in Service," Proceedings, American Concrete Institute, Vol 27, May 1931, pp 1065-1090.

The Hydro-Electric Power Commission of Ontario decided, some years ago, to systematically study the behavior of their many concrete structures with a view to learning not only their existing condition, but their probable condition in years to come. The examinations were extended to include other concrete structures in different parts of Canada and the United States until the number of inspections now made has reached a total of several hundred. This paper is an attempt to set down briefly some of the conclusions that have been reached as a result of these examinations.

<u>1936</u>

A-4 Scholer, C. H., "Studying the Durability of Concrete," Proceedings, American Concrete Institute, Vol 32, May-Jun 1936, pp 593-607.

A general discussion of the problem of concrete durability. The various components of concrete, the method of handling, placing, finishing, and curing and the inter-relationship of these factors and the effects of each on the character of the concrete are considered.

Methods of studying durability in the laboratory and the field and some of the variables to be evaluated in such studies are briefly presented.

A-5 Gonnerman, F. G., Timms, A. G., and Taylor, T. G., "Effect of Calcium and Sodium Chlorides on Concrete When Used for Ice Removal," Proceedings, American Concrete Institute, Vol 33, Nov-Dec 1936, pp 107-122.

Reports relative values of various types of surface coatings in preventing scaling of young concrete (12 x 12 x 2-1/2-in.* test slabs) when calcium and sodium chlorides were used for ice removal. Of the surface coatings tried, only two, linseed oil and soy bean oil, were of much value. The best surface coating consisted of turpentine, applied at the rate of about 50 sq yd per gal., followed after 24 hr by the application of straight boiled linseed oil at the rate of about 70 sq yd per gal.

A-6 Tuthill, L. H., "Resistance of Cement to the Corrosive Action of Sodium Sulfate Solutions," Proceedings, American Concrete Institute, Vol 33, Nov-Dec 1936, pp 83-106.

Describes investigations leading to preparation early in 1935 of one of the first (if not the first) consumer specifications for purchase of sulfate resisting cement. Cements from a wide range of compositions were tested. From evidence of their relative resistance to corrosion in sodium sulfate solutions, it appeared that a cement having a composition with maximum limits of 4 percent for C_3A, 12 percent for C_3A

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is given on page 4.

plus C_4AF, and 50 percent for C_3S would be highly sulfate resistent. Subsequent tests have proved cement manufactured under such a specification to be much more resistant to sulfate corrosion than cements of other composition.

1938

A-7 Blanks, R. F., Meissner, H. S., and Rawhouser, C., "Cracking in Mass Concrete," Proceedings, American Concrete Institute, Vol 34, Mar-Apr 1938, pp 477-496.

Includes descriptive matter and tests on the cause and control of cracking, temperature variation, and thermal stress and volume change, based on design and research work of the Bureau of Reclamation. Structures studied include Owyhee, Boulder, Grand Coulee, Norris, Bartlett, and Morris dams and other smaller dams. Shrinkage studies of test bars and cylinders are described and results indicated. The most effective single method for improving cracking conditions is the use of low-heat or portland-pozzolan cement.

A-8 Miller, D. G., "Factors Which Influence the Durability of Concrete Stave Silos," Proceedings, American Concrete Institute, Vol 34, Mar-Apr 1938, pp 381-400.

Effect of weathering and silage action on some 200 masonry silos in Iowa, Minnesota, South Dakota, and Wisconsin is reported based on field investigation. Silage action is described in detail. Tests of the 1350 silo staves collected from nine different plants also are reported. Tests include determination of effect of cement factor on strength and absorption of staves, relation of permeability and absorption to strength of staves, and the effect of number or tamps.

A-9 Stanton, T. E., Jr., and Meder, L. C., "Resistance of Cements to Attack by Sea Water and by Alkali Soils," Proceedings, American Concrete Institute, Vol 34, Mar-Apr 1938, pp 433-464.

Premature disintegration of California pavements occasioned investigation of alkali soils and their effect on concrete. Analysis of alkali content of several California soils

are presented. Test specimens made with 11 cements commercially available in California were subjected to varying degrees of exposure to sea water and alkali soils. Compressive strengths and weight losses are recorded, indicating effect of chemical composition of cement on alkali resistance. Specific results apply to California cements, but major trends should be of general interest.

A-10 ACI Committee 804, "Concrete Wearing Surfaces for Floors," Proceedings, American Concrete Institute, Vol 35, Sep 1938, pp 21-32.

Data and recommendations on concrete floor surfaces for hard wear, with record of new accelerated tests; suggests a specification outline for materials and workmanship both held within narrow limits. A departure from usual practice is presented for criticism.

1939

A-11 Wuerpel, C. E., "Tests of the Potential Durability of Horizontal Construction Joints," Proceedings, American Concrete Institute, Vol 35, Jan 1939, pp 181-188.

Presentation is made of freezing and thawing tests on 4- and 6-in.-diam. concrete cores, containing horizontal construction-joint planes, removed from hydraulic structures. The results indicate (1) that such joints are highly resistant to deterioration by frost action when carefully cleaned with air and water jets, (2) that deterioration due to frost is most likely to develop in the zone of concrete immediately below the joint plane if material water gain occurred in the concrete mixture. The tests were intended to supplement permeability and flexural strength tests on similarly prepared joints by other agencies.

A-12 Carlson, R. W., "Remarks on Durability of Concrete," Proceedings, American Concrete Institute, Vol 35, Apr 1939, pp 359-364.

A statement of factors affecting the durability of concrete; the fatigue action of volume changes produced by changes

in temperature and moisture; the freezing of water in the pores of concrete; the phenomenon of bleeding; the thermal, elastic, and hygral properties of the consitutents of concrete. Emphasis is placed on the need for test methods which will permit more accurate prediction of durability.

A-13 Marshall, S. W., "Durability of Pavement Concrete - Experience in Pennsylvania," Proceedings, American Concrete Institute, Vol 35, Apr 1939, pp 393-404.

Reports data obtained from a comprehensive survey of concrete highway paving slab behavior in three adjacent Pennsylvania areas differing appreciably in climate. Quality of concrete aggregate also varies considerably in the different areas. Observations were made from standpoints of surface condition and structural condition of the paving slab, three classes (or stages) of failure recognized. In general, check surveys confirmed original findings. A marked increase in rate of concrete deterioration is noted as climatic conditions become more severe. Concrete in all three areas is subjected to an appreciable amount of freezing and thawing but in one area the weather conditions are particularly severe. In the area of severest weather the quality of concrete aggregate is lower than in the others and heaving of subgrade is more prevalent. Existence of many factors influencing concrete paving slab durability is recognized but no attempt is made to interpret results of the survey in detail. Results suggest that present conceptions of the useful life of concrete pavement may require modification for localities in which many of the factors involved may be unfavorable to the lasting qualities of concrete.

A-14 Welden, E. C., "Durability of Pavement Concrete - Experience in Connecticut," Proceedings, American Concrete Institute, Vol 35, Apr 1939, pp 405-416.

Connecticut practice in the construction of concrete pavements has seen many changes, both in design and methods of construction. Since the early twenties coarse and fine aggregates of good quality have been readily available. The use of a gravel or stone base under the pavement, and also the minimum amount of water necessary for workability of the

concrete, has had much to do with the relatively good conditions of the pavement concrete. Expansion joints and fillers in many cases have proved disappointing. Experience to date indicates that the use of vibrators with mixes of the proper consistency will improve the quality and durability of pavement concrete.

A-15 Lawton, D. C., "Durability of Concrete Pavement - Experience in New York State," Proceedings, American Concrete Institute, Vol 35, Jun 1939, pp 561-580.

A resume of field behavior of some 440 miles of concrete pavement constructed for experimental purposes by New York State with different proportions and combination of aggregates. Field service records of these pavements were made and compared with laboratory tests of aggregates used. The purpose was to study the durability of cement concrete pavement as affected by coarse aggregate such as stone, gravel, and slag; as affected by sands of different characteristics, such as high and low kaolin; and as affected by blended cement composed of different proportions of natural and normal portland cements. The projects studied were identified by name and listed.

A-16 Withey, M. O., "Factors Affecting the Resistance to Freezing and Thawing of Vibrated Concrete Made of Crushed Dolomite," Proceedings, American Concrete Institute, Vol 35, Jun 1939, pp 553-560.

Reports effect of 150 cycles of freezing and thawing on the flexural and compressive strength of 100 concrete prisms. Little or no damage was suffered by concrete with 0.54 water-cement ratio, by weight containing 4-3/4 sacks of cement per cu yd. The flexure test was a far more sensitive measure of resistance to freezing and thawing than the compression test.

1941

A-17 Meissner, H. S., "Cracking in Concrete Due to Expansive Reaction Between Aggregate and High-Alkali Cement as Evidenced in Parker Dam, Proceedings, American Concrete Institute, Vol 37, Apr 1941, pp 549-568.

Excessive expansion has been recognized for some time as causing that type of concrete distress manifested by a characteristic random-pattern cracking. Recent disclosures point to an additional new explanation in the chemical reaction between high-alkali cement and the mineral constituents of certain aggregates. It is possible that many failures, which have been incorrectly interpreted, may ultimately be clarified when analyzed for this suspected action.

Paper describes a chain of circumstancial evidence which connects one case of deteriorating concrete with this type of action. The cement used was known to have contained large amounts of soda and potash. After considerable research it was discovered that the natural sand and gravel contained small amounts of andesite and rhyolite, which were reacting in the concrete with such cement. Part of the evidence was a gel substance, a by-product of the reaction, identified as sodium silicate.

A-18 Tremper, B., "Evidence in Washington of Deterioration of Concrete Through Reaction Between Aggregates and High-Alkali Cements," Proceedings, American Concrete Institute, Vol 37, Jun 1941, pp 673-688.

Deterioration of concrete in two areas in Washington is described. Unsatisfactory results are connected definitely with combinations of certain aggregates and cements. The aggregates when used with other cements and the cements when used with other aggregates have produced concrete of satisfactory durability. Evidence indicates that with these aggregates, the cements that were used in durable concrete were low in alkali and those used in concrete which has deteriorated were high in alkali. Investigations have not been completed, however, and there is some evidence of a negative nature.

A-19 Pearson, J. C., "A Concrete Failure Attributed to Aggregate of Low Thermal Coefficient," Proceedings, American Concrete Institute, Vol 38, Sep 1941, pp 29-36.

Gives the highlights of an investigation to account for a rapid failure of some cast stone steps in the winter of 1937-38. Preliminary studies of the cement, aggregate and

concrete gave no clue to the trouble except to show that the aggregate in some way caused rapid failure of the concrete in freezing and thawing tests. Eventually the aggregate was found to have an unusually low thermal coefficient, although resistant to frost action in itself. A number of other low coefficient aggregates were found, and in concrete subjected to freezing and thawing tests, all produced the same type of rapid failure. Such aggregates evidently produced high internal stresses at low temperatures and made the concrete particularly vulnerable to frost action.

1942

A-20 Hughes, C. A. and Anderson, K. A., "Observations of the Durability of Dry Tamped Silo Staves," Proceedings, American Concrete Institute, Vol 38, Jan 1942, pp 237-252.

From data obtained by subjecting cubes cut from dry-tamped silo staves to durability cycles consisting of frost action alone or a combination of frost and acid action, it is concluded that the transverse strength and absorption are not adequate criteria of the durability of dry-tamped silo staves. From a discussion of exposure conditions and evidence obtained from field inspection, it is concluded that frost action is the chief factor in silo durability though acid action is still important because of its accelerating effect of the rate of disintegration in freezing and thawing tests. The procedure for a durability acceptance test is proposed.

A-21 Thomas, H. A., "Cavitation in Outlet Conduits of High Dams," Transactions, American Society of Civil Engineers, Vol 107, 1942, p 421.

Occurrence of severe cavitation damage to the concrete surfaces of the outlet conduits of the Madden Dam in the Panama Canal Zone supplied the incentive to carry on extensive studies by means of laboratory models to investigate the cavitation potentialities, if any, in the conduits of the Tygart River Dam near Grafton, W. Va., and to develop methods of eliminating or minimizing future damage in the conduits of the Madden Dam. Similar studies, on a less elaborate scale, were conducted in connection with the design of the Bluestone Dam in West Virginia, Hiwassee Dam in North Carolina, and Redbank Creek Dam in Pennsylvania.

The development of cavitation-testing facilities of two types, known respectively as the "enclosed-tank apparatus" and the "diverging-tube apparatus," is described, and the hydraulic theory pertinent to the making of cavitation tests in these facilities is presented. A description is given of cavitation studies conducted on models of the conduit entrances of the Madden Dam.

1943

A-22 Alderman, A. R., "Review of Evidence Concerning Expansive Reaction Between Aggregate and Cement in Concrete," Bulletin No. 161, 1943, Australia Council for Scientific and Industrial Research.

Review of evidence and opinions concerning reaction between aggregate and cement which have so far been published: original observations of T. E. Stanton; evidence from Parker Dam; other evidence; later investigations; published discussions are all brought together in one bulletin.

1944

A-23 Tremper, B., "The Effect of Alkalies in Portland Cement on the Durability of Concrete," Proceedings, American Concrete Institute, Vol 41, Nov 1944, pp 39-104.

Field observations, now confirmed by laboratory tests, have demonstrated the reactive character of concrete aggregates derived from lavas of the volcanic cone of Mt. Rainier, Wash. Deterioration has been universal in concrete containing such aggregates and high-alkali cement but when low-alkali cements have been used structures are in excellent condition at ages up to 19 years. The rate of retrogression is dependent on the severity of climatic conditions.

Disintegration of another type is progressing in certain structures in eastern Washington. Reactivity of the aggregates used is not exhibited in the sealed-can test but may be demonstrated by a combination of moist storage followed by cycles of freezing and thawing. The main, if not the sole, factor influencing disintegration in this test is the content of alkalies in the cement whether they are present initially or are added at the time of mixing.

These results point to the need of limiting the alkali content of cements for satisfactory use with many aggregates in Washington.

1945

A-24 Rawhouser, C., "Cracking and Temperature Control of Mass Concrete," <u>Proceedings, American Concrete Institute</u>, Vol 41, Feb 1945, pp 305-348.

Presents a discussion of certain characteristics of mass concrete which have assumed increased importance in recent years by reason of more rapid construction with modern equipment of extremely large concrete dams. Understanding of the factors affecting the temperature and the thermal stresses of mass-concrete structures is necessary if advantage is to be taken of control measures to prevent unfavorable conditions. Some of the more important factors are presented which combine to establish controlling conditions of temperature, volume change, and crack development. A section on temperature computations is included which presents methods of evaluating the effects of imposed conditions and of determining the nature and extent of the temperature control required.

1946

A-25 Blanks, R. F. and Meissner, H. S., "Deterioration of Concrete Dams Due to Alkali-Aggregate Reaction," <u>Transactions, American Society of Civil Engineers</u>, Vol III, 1946, p 743.

For many years engineers have been concerned over a peculiar and characteristic type of concrete deterioration, manifested by large-scale, random-pattern cracking. Such cracking is not unusual or new; in fact it is difficult to find massive concrete structures that do not display random cracking in some degree. Most instances of pronounced pattern or map cracking, as distinguished from ordinary small-scale crazing, have been attributed to shrinkage. The mechanisms producing internal expansion have been explained in the past on the basis of unsound aggregate or unsound cement, the latter resulting from high magnesia content or underburning and high free-lime content. Although some instances of expansive deterioration appear to be explained adequately by unsoundness,

most cases, until recently, have remained inigmas and subjects for speculation only. Many concrete dams in all sections of the United States have developed evidence of this type of degeneration. Several of these cases have been caused by adverse chemical reactions between the alkalies in Portland cement and certain siliceous mineral constituents in the aggregates.

Identification of alkali-aggregate reactions as the cause of many cases of concrete deterioration has been recorded in contemporary technical literature. A brief selected bibliography is included as an Appendix of this paper. The destructive effects of the chemical instability of some aggregate constituents to the presence of alkalies contained in Portland cements have been definitely established. The problem is extremely complicated, however, and many questions, practical and technical, remain to be answered satisfactorily.

A-26 Jackson, F. H., "Durability of Concrete in Service," Proceedings, American Concrete Institute, Journal, Vol 43, No. 2, Oct 1946, pp 165-180.

This paper discusses the problem of concrete durability with reference primarily to highway bridge structures located in regions subject to severe frost action. Four major types of deterioration are defined and illustrated and several specific matters which have bearing on the problem, including the effect of construction variables, modern vs. old fashioned cements, air entrainment and the so-called "cement-alkali" aggregate reaction, are discussed. The report concludes with a series of recommendations indicating certain corrective measures which should be taken.

1947

A-27 Harrold, J. C., "Cavitation in Hydraulic Structures: A Symposium; Experiences of the Corps of Engineers," Transactions, American Sosiety of Civil Engineers, Vol 112, 1947, pp 16-42.

The discovery, in 1935, of severe pitting of the concrete in the conduit entrances of Madden Dam on the Chagres River in the Isthmus of Panama prompted the Corps of Engineers, U. S. Army, to undertake later that year a program of model research on the subject of cavitation. The initial purpose of this

research was to develop a design of conduit entrance that would be free from cavitation. The program was later expanded to include a study of cavitation at gate slots in conduits and cavitation around baffle piers in stilling basins of high dams. The major part of this paper is devoted to a discussion of this model research and its effect on the design of structures that come under the jurisdiction of the Corps of Engineers.

The first research was conducted at Carnegie Institute of Technology at Pittsburgh, Pa., under the direction of Harold A. Thomas, M. ASCE. Later the U. S. Waterways Experiment Station at Vicksburg, Miss., joined in the study. Since 1941 both laboratories have been engaged in cavitation research for the Corps of Engineers. At Carnegie Institute of Technology models are tested in a vacuum tank in which the air pressure can be reduced to scale and in which actual cavitation can be made to occur. At the U. S. Waterways Experiment Station, ordinary open-air models are used and cavitation pressures are detected with especially designed electric pressure cells capable of measuring rapidly fluctuating pressures in water. These cells are attached to piezometer openings in the face of the model. Both methods have proved highly satisfactory and the results obtained at both laboratories have been correlated.

A-28 Warnock, J. E., "Cavitation in Hydraulic Structures: A Symposium; Experiences of the Bureau of Reclamation," Transactions, American Society of Civil Engineers, Vol 112, 1947, pp 43-58.

With the trend to larger and larger hydraulic structures, cavitation and the resultant pitting have become major problems to the hydraulic designing engineer. Subatmospheric pressures in smaller structures were of little consequence, but with the increase of head in more recent structures, the approach of subatmospheric pressures with absolute zero as their limit has created previously unheard of situations. Experience in the laboratory and in the field shows that prevention of cavitation is fundamentally a function of design.

A-29 Hickox, G. H., "Cavitation in Hydraulic Structures: A Symposium; Experiences of the Tennessee Valley Authority," Transactions, American Society of Civil Engineers, Vol 112, 1947, pp 59-70.

This paper describes cavitation damage experienced by the Tennessee Valley Authority (TVA) in the sluices of Norris Dam, the repairs made to the damaged areas, and the steps taken to prevent similar damage in other structures built by the TVA.

A-30 Steele, B. W., "Cracks in Concrete," Proceedings, American Concrete Institute, Journal, Vol 43, Feb 1947, pp 629-636.

Cracks in concrete that are irregular and uncontrolled are objectionable. If causes were better understood, the elimination of cracks would be less difficult. Cracks are mainly due to one or more of the following causes: 1) lack of adequate investigation of all of the ingredients involved; 2) lack of sufficient advance planning to obtain satisfactory results; 3) lack of team work in the human element involved in this intricate manufacturing process; and 4) lack of teamwork (compatibility) in the ingredients, which include alkali aggregate reaction and the use of argillaceous limestone and chert as aggregate. The modern laboratory's test procedure will not condemn many limestones and cherts that are capable of starting surface cracking. The elimination of unsound types is not at all a simple procedure. A suggested A-B-C procedure is offered toward the partial elimination of cracks: A) to establish approved sources of aggregate with good service records; B) thoroughly investigate new sources of supply, subjecting them to all known tests including analysis by a petrographer; and C) study the design of every structure proposed with a view towards eliminating structural cracks by proper control of the design of the mix and the placing of the concrete and provide relief from volume change tensile stresses with designed cracks placed where they will not be objectionable.

A-31 Weiner, A., "A Study of the Influence of Thermal Properties on the Durability of Concrete," Proceedings, American Concrete Institute, Journal, Vol 43, May 1947, pp 977-1008.

An attempt is made to rationalize the effect of air content and type of aggregate on the durability of concrete by a consideration of the thermal properties. The principal thermal properties of plain, Vinsol resin, and neutralized Vinsol resin concrete made with siliceous gravel and with trap-rock

under two mixing conditions (air and vacuum-mix) are presented. The increased durability developed by addition of an air-entraining admixture does not appear to be a result of the slight change in thermal properties accompanying air entrainment. When differences in thermal diffusivity exist between mortar and coarse aggregate, rapid freezing and thawing may cause failure by internal expansion. This paper should be considered as a progress report on the subject and the conclusion set forth as tentative; subject to verification by the results of further study.

A-32 Tremper, B., "The Corrosion of Reinforcing Steel in Cracked Concrete," <u>Proceedings, American Concrete Institute, Journal</u>, Vol 43, Jun 1947, pp 1137-1144.

Sixty-four small concrete blocks containing steel wires and deformed bars as reinforcing were loaded as beams to produce cracks normal to the direction of the steel. After ten years outside exposure, the steel specimens were removed from the concrete and examined for the amount of corrosion. Corrosion was found for short distances in the region of the cracks but was too minor in degree to be considered of serious consequence.

A-33 Price, W. H., "Erosion of Concrete by Cavitation and Solids in Flowing Water," <u>Proceedings, American Concrete Institute, Journal</u> Vol 43, No. 9, May 1947, pp 1009-1023.

High velocity water jet and shot-blast tests which were made to determine the effects of mix proportions, curing, absorptive form lining, air entrainment and surface finish on the erosion resistance of concrete are described. Examples of erosion failures in hydraulic structures by wear and cavitation and methods of repair are included.

A-34 Lyse, I., "Deterioration of Concrete in Brine Storage Tanks," <u>Proceedings, American Concrete Institute</u>, Vol 44, Oct 1947, pp 141-148.

A survey in Norway revealed serious deterioration of concrete storage tanks for low-temperature NaCl and $CaCl_2$ brine. Laboratory tests indicated deterioration was caused by low temperature rather than brine action alone. It is believed that the brine pentrates the concrete, producing a salt solution which varies from relatively high concentration at the surface to low concentration some distance within. Low brine temperature will produce freezing of the water of the concrete except where salt concentration is sufficient to prevent it. At a certain depth from the surface, salt concentration will be just sufficient to give an equilibrium between freezing and no freezing of the water. Here there will be a continual freezing and thawing action as the brine temperature changes a few degrees. Such action causes rapid disintegration. Suggested remedies are thorough drying to remove water near surface of concrete, and a seal coat to prevent brine penetration.

A-35 McConnell, D., Mielenz, R. C., Holland, W. Y., and Breene, K. T., "Cement-Aggregate Reaction in Concrete," Proceedings, American Concrete Institute, Vol 44, Oct 1947, pp 93-128.

The chemical interaction of certain rocks and minerals of aggregate with high-alkali portland cements is known to have caused serious distress of concrete structures in California, Oregon, Idaho, Arizona, Nebraska, Kansas, Washington, Wyoming, Virginia, and New York. Similar distress will undoubtedly be discovered in other states. Microscopic, microchemical and physical-chemical studies of concrete have revealed the detailed characteristics of the deterioration, and make possible the distinction of this type of deterioration from others. Petrographic and physical-chemical investigations have identified the rocks and minerals which are susceptible to attack by cement alkalies.

The expansion and cracking of the concrete result from osmotic pressures developed in alkalic silica gels that are produced by partial dissolution of siliceous rock and mineral substances. Laboratory experiments and calculations indicate that these osmotic pressures exceed 550 psi.

1948

A-36 Parsons, W. H. and Insley, H., "Aggregate Reaction with Cement Alkalies," Proceedings, American Concrete Institute, Vol 44, Apr 1948, pp 625-632.

Experiments reported tend to support and amplify Hansen's hypothesis on alkali-aggregate reaction. Test specimens composed of high-alkali cement and reactive aggregate (opal) were exposed to conditions prompting the reaction resulting in cracking and expansion. Petrographic examination at frequent intervals during the course of exposure indicated that the chemical reaction results in liquefaction, swelling, and migration of the reaction products. The liquefied gel produced by the reaction fills pores existing in the specimen. After the pore is filled, a reaction at the pore wall occurs to form a dense, semipermeable membrane through which osmosis takes place, resulting in expansion and cracking.

A-37 Stanton, T. E., "Durability of Concrete Exposed to Sea Water and Alkali Soils - California Experience," Proceedings, American Concrete Institute, Journal, Vol 44, May 1948, pp 821-848.

This article is a continuation of a discussion on the same subject published in the ACI Journal for March-April 1938. Data not available at that time which have since come to light contribute materially to our understanding of the causes of concrete deterioration when exposed to sea water and alkali soils and appropriate corrective or protective measures.

The principal new developments are:

1. The discovery that one cause of excessive expansion and cracking of concrete is an adverse reaction between certain minerals in the aggregate and the alkali constituents of portland cement, thereby providing an avenue for the ingress and deposit of aggressive salts in excessive amounts. The cure in this case is to use either a nonreactive aggregate or a low alkali or suitable portland-pozzolan cement.

2. Positive evidence that the resistance of concrete to sulfate attack is materially improved through the use of a suitable air entraining agent. Accelerated tests indicate the ASTM approved air-entraining agents, Vinsol resin and Darex, are suitable and effective.

A-38 Terzaghi, R. D., "Concrete Deterioration in a Shipway," Proceedings, American Concrete Institute, Vol 44, Jun 1948, pp 977-1008.

Concrete in the gate structure of a large submerged shipway in the southeastern United States began to deteriorate 2 years after construction was completed. The defects included abnormally low strength of some of the concrete and numerous cracks which became progressively wider. An investigation of the cause of deterioration, begun at this time, included microscopic examination and chemical analyses of core specimens, chemical analyses of specimens of water issuing from relief pipes in the pier, frequent crack surveys, periodic measurement of change of length of the pier and change of width of two of the chief cracks, and compression tests on selected core specimens. On the basis of the data obtained by these various methods, it was concluded that detrimental processes of two types are taking place in the concrete. One of these causes expansion of the central part of the pier and thus leads to cracking at the pier surface. This process is ascribed to a reaction between hydrated cement and sulfates and/or other substances normally present in sea water. The other process produces a local softening or even complete disintegration of the concrete. It appears to be due chiefly to a chemical reaction between the paste and carbon dioxide which is present in unusually high concentration in the water percolating through the structure.

A-39 Scripture, E. W. and Sakryd, C. H., "Corrosion Resistance Tests of Concrete Floors With and Without Metallic Aggregate," Proceedings, American Concrete Institute, Vol 45, Dec 1948, pp 317-324.

An attempt has been made to determine the conditions under which concrete floors can be expected to give good service. Resistance to abrasion was determined on specimens with and without metallic aggregate after exposure to typical reagents selected from the groups described by the Joint Committee as having corrosive effects of an intermediate nature between no attack and severe attack. On the basis of the experimental results the reagents in the Joint Committee report have been classified in relation to anticipated service of concrete floors.

1949

A-40 Terzaghi, R. D., "Concrete Deterioration Due to Carbonic Acid," Journal, Boston Society of Civil Engineers, Vol 36, No. 2, Apr 1949, pp 136-160.

In many regions, ground water and/or surface water, such as that of streams, lakes, or marine estuaries, contains a considerable quantity of free carbon dioxide. Under certain circumstances, a part of this, known as "aggressive carbon dioxide," can attack concrete. The ratio of aggressive carbon dioxide to total carbon dioxide varies with the concentration of carbon dioxide, calcium bicarbonate and other dissolved substances. For a given concentration of carbon dioxide and calcium bicarbonate, the ratio is much greater for sea water than for fresh water. Experience shows that attack is likely to be sufficiently rapid to require consideration if the concentration of aggressive carbon dioxide exceeds about 20 ppm. The rate of attack and the severity of deterioration is increased by the presence of other deleterious substances, such as sulfates. Attack may be prevented by treating the water, for instance by allowing it to react with calcium carbonate before it comes in contact with concrete; it may also be prevented by maintaining an impervious coating on all surfaces exposed to deleterious water. If sulfates as well as aggressive carbon dioxide are present, the use of sulfate-resisting cement is recommended.

A-41 Price, W. H. and Wallace, G. B., "Resistance of Concrete and Protective Coatings to Forces of Cavitation," Proceedings, American Concrete Institute, Vol 46, Oct 1949, pp 109-120.

A machine used for producing cavitation erosion in the laboratory is described and the results of tests made to investigate the effect of mix proportions, surface treatment, and protective coatings on the resistance of concrete to cavitation are discussed. Through proper use of these, the resistance of concrete surfaces to cavitation erosion may be extended three or four times, but even the best concrete will not resist the forces of cavitation for a prolonged period. Heavy rubber coatings bonded well to the surface of the concrete have proved effective.

1950

A-42 Pietta, D. H., Massie, E. F., and Robins, H. S., "Corrosion Protection of Thin Precast Concrete Sections," Proceedings, American Concrete Institute, Vol 46, Mar 1950, pp 513-528.

A new electrical resistance technique for measuring the rate of corrosion of steel reinforcing is described. The method employs a thin ribbon 0.008 by 0.25 in. as the resistance element embedded in 6 by 12 in. thin panels, and a Kelvin bridge sensitive to 0.0001 ohm. The data plotted in dimensionless parameter form enable the half-life of concrete to be determined at a comparatively early age. The term half-life is defined as the time required for the cross-sectional area of the reinforcing to decrease by one-half its original value due to corrosion. Six mixes, three water-cement ratios, four exposure conditions, and three depths of cover were examined.

A-43 Alderman, A. R., Gaskin, A. J., Jones, R. H., and Vivian, H. E., "Australian Aggregates and Cements in Relation to Cement-Aggregate Reaction," Proceedings, American Concrete Institute, Vol 46, Apr 1950, pp 613-616.

A wide variety of Australian aggregates and cements has been examined with a view to estimating the possible incidence of expansive reaction in concrete made from these materials.

Mortar bars were observed over periods up to 2 years and the results correlated with petrographic examination of the aggregates and chemical composition of the cements. This correlation has shown that in most cases the potential reactivity can be assessed by petrographic examination but that doubtful material requires supplementary mortar tests.

A-44 Vivian, H. E., "Some Australian Studies on Cement-Aggregate Reaction in Mortar," Proceedings, American Concrete Institute, Vol 46, Apr 1950, pp 617-624.

Summarizes briefly some of the papers on cement-aggregate reaction which have been published by the Commonwealth Scientific and Industrial Research Organization in Australia. These papers deal with four aspects of mortar expansion; the change in mortar tensile strength as expansion occurs, and the effects of alkali mobility, void space in the mortar, and different storage conditions on mortar expansion.

A-45 Clark, R. R., "Effects of High-Velocity Water on Bonneville Dam Concrete," Proceedings, American Concrete Institute, Vol 46, Jun 1950, pp 821-840.

This paper compares the progressive erosion which has taken place in the stilling basin of Bonneville Dam with that anticipated in the design, together with the repairs that have been made and the effect on the repairs of the action of high-velocity water.

1951

A-46 Scripture, E. W., Jr., Benedict, S. W., and Litwinowicz, F. J., "Air Entrainment and Resistance to Freezing and Thawing," Proceedings, American Concrete Institute, Vol 48, Dec 1951, pp 297-308.

Investigations were undertaken to determine the suitability of various air-entraining agents for use in concrete, the relative effects of slow and rapid cycles of freezing and thawing, and the optimum range of air contents for concrete. With normal air-entraining agents the resistance to freezing and thawing varies mainly with the air content, not with the particular agent used. A rapid freezing and thawing cycle is considerably more destructive than a slow cycle, and abnormal results appear to be produced in some cases by a very fast cycle. With increasing entrained air, resistance to freezing and thawing increases to a maximum and thereafter no further benefit appears to be secured. The optimum amount seems to be about 2-1/2 to 3 percent added entrained air.

A-47 Barona De La O, F., "Alkali-Aggregate Expansion Corrected with Portland-Slag Cement," Proceedings, American Concrete Institute, Journal, Vol 47, 1951, pp 545-552.

Granulated basic blast furnace slag meeting ASTM Spec. C205 should not be considered a pozzolan, but a latent cement with a high siliceous glass content requiring the presence of hydrated lime and gypsum for hydration. To correct alkali-aggregate expansion, a high proportion of slag (50 to 60 percent) which does not reduce strength should be used rather than lower percentages (20 to 30) which can not be exceeded with

pozzolans unless strength is sacrificed. Corrective action was investigated using Pyrex glass as reactive aggregate, and NaOH to increase the alkali content of the different cements and blends to the same high value (1.23 percent).

Under similar conditions, with the same high alkali content, much smaller expansions were obtained with slag blends than with straight portlands. It is not intended to compare or recommend the use of slag instead of pozzolans, or the use of portland-blast furnace slag cement instead of modified, low-heat, or sulfate resistant cement, since in each case, the availability, cost, and special conditions will determine what to use. In many cases, slag can be used advantageously to replace 50 to 60 percent of portland clinker.

A-48 McCoy, W. J. and Caldwell, A. G., "New Approach to Inhibiting Alkali-Aggregate Reactions," Proceedings, American Concrete Institute, Journal, Vol 47, 1951, p 693.

Investigators have studied for a decade the chemical reactions between high-alkali cement and siliceous mineral consituents of some aggregates toward deterioration of concrete. Papers on this subject indicate a consensus that there are just two possible remedial measures when reactive aggregates are used - low-alkali cement or substitution of a pozzolanic material for 20 to 30 percent of the portland cement.

Investigative work focused off the beaten path of pozzolans and lowering cement alkali content resulted in experimental data which indicate that small amounts of certain materials added to high-alkali cement have an inhibiting effect on expansion reaction. For example, it has been found that 1 percent of less of specific salts will reduce expansion more than 75 percent in Pyrex glass mortar bar tests. This reduction was substantiated by similar mortar bar tests using a small percentage of opal and quartz sand as aggregate.

Additional information indicates that small amounts of certain proteins (0.2 percent or less) added to the cement appear to have a greater inhibiting effect on the expansive reaction than is obtained by comparable air entrainment effected by the conventional air-entraining agents.

Such inhibitors appear to have no appreciable detrimental effect on the properties of the high-alkali cements as determined by ASTM specification tests for cement.

1952

A-49 Callan, E. J., "Thermal Expansion of Aggregates and Concrete Durability," Proceedings, American Concrete Institute, Vol 48, Feb 1952, pp 485-504.

Differences in durability of concretes containing aggregates from the same source and similar concretes containing different fine and coarse aggregates are explained partially by differences in thermal expansion of the coarse aggregate and the mortar. Methods were developed to obtain simply the thermal coefficients for numerous aggregates. Concretes were tested in accelerated freezing and thawing, yielding durability factors (DFE) for each combination. The DFE's were statistically analyzed with the difference between the thermal coefficients of coarse aggregates and mortars (Δc) and coarse aggregate absorption (A) as variables. For 78 concrete combinations a relation DFE = 109.65 - 8.76 Δc - 15.22 A was developed with a correlation coefficient of 0.719 which is highly significant. Thus, the durability of these concretes was reduced when the differential expansion of mortar and coarse aggregate increased. Stresses set up by such differential expansion and their effects on concrete durability are discussed briefly. It is concluded that thermal effects of this type should be considered in choosing aggregates for highly durable concretes. The methods developed for determining coefficients of thermal expansion of coarse aggregate and mortar are described.

A-50 Porter, C. B., Gilmore, R. W., Jackson, F. H., Tuthill, L. H., and Steele, B. W., "Durability," Proceedings, American Concrete Institute, Vol 48, May 1952, pp 725-752.

Report on conditions affecting durability of concrete structures and discussion of design modifications and changes in construction and maintenance procedures to prolong their useful life.

Surveys of structures of various ages and an evaluation of factors affecting their durability. Brief report of research on testing and developing waterproofing materials. A brief discussion of the factors that control durability of concrete pavements. Structural performance and durability are defined and their relationship to each other and to water-cement ratio brought out. The role of air entrainment in

improving the durability of concrete pavements, particularly under the attack of chloride salts used for ice removal, is discussed and thinking on the subject summarized.

The necessity of controlling volume change and providing impermeability in mass concrete hydraulic structures contributes to the problems of durability. Mix proportioning, placement methods, use of admixtures, and other measures to increase the serviceability of such work are considered. The need for impermeable concrete is stressed as the primary requirement for lasting durability of mass hydraulic structures. Research in all phases of concrete mix and design is recommended as the answer to the need for a method of evaluating permeability in regard to its permanent effect on the durability of concrete thus establishing a realistic approach to specifying cement content of concrete mixtures in which strength is of secondary importance.

<u>1954</u>

A-51 Hansen, W. C., "Effect of Age of Concrete on its Resistance to Scaling Caused by Using Calcium Chloride for Ice Removal," <u>Proceedings, American Concrete Institute</u>, Vol 50, No. 5, Jan 1954, pp 341-351.

Tests were made in the field to determine the effect of age of concrete, at the time of the first application of de-icing salt, on the resistance to frost and salt action. Slab specimens, 36 by 36 by 6 in., were provided with dikes which permitted the freezing of approximately 3/8 in. of water on their surfaces. Specimens were made with Types I and IA cements and a blend of the two cements, which yielded concretes having air contents of approximately 1.5, 3.0, and 5.0 percent, respectively. Ice was removed by applications of flake calcium chloride whenever the 3/8 in. of water was frozen solid. A total of 55 cycles of freezing and thawing were obtained in the one winter.

Except for the specimens which were 117 and 91 days old, respectively, at the first freeze, those made with concrete containing approximately 1.5 percent air were completely scaled in from 5 to 15 cycles of freezing and thawing. Complete scaling was obtained in less than 55 cycles of freezing and thawing with the concrete containing approximately 3 percent air only on specimens which were 29 days old or less at the time of the first freeze, and with concrete containing approximately 5 percent air only on specimens which were 8 days old or less at the first freeze.

A-52 Woods, H., "Observations on the Resistance of Concrete to Freezing and Thawing," Proceedings, American Concrete Institute, Vol 51, Dec 1954, pp 345-352.

A survey and analysis of the more important investigations on freezing and thawing of concrete show that significant general conclusions can be drawn. Some of these conclusions are presented in a manner designed to show their reasonableness, but without data-led evidence.

1955

A-53 Halstead, S. and Woodworth, L. A., "The Deterioration of Reinforced Concrete Structures Under Coastal Conditions," Transactions, South African Institution of Civil Engineers, Vol 5, No. 4, Apr 1955, pp 115-134.

The first part of this paper describes the deterioration of certain reinforced concrete structures located near the sea on the South Coast of Natal. The structures are exposed to the marine atmosphere and the hot, humid, sub-tropical climate experienced in this area. The progress of the corrosion of the steel reinforcement embedded in the concrete is described through four distinct stages from an initial stain on the surface of the concrete to complete disintegration of the steel. The general problem is stated and serves as an introduction to the experimental work described in Part II.

The second part describes in detail laboratory investigations on the chemical and electro-chemical aspect of corrosion. It is shown how self-generated currents are induced in steel reinforcement when salt concentrations in the concrete are not uniform, and the conclusion is drawn that if the salt concentration can be maintained above a certain level the currents are reduced to a negligible value. When induced currents are inhibited no corrosion takes place. Difference in moisture content and its relation to induced currents and corresponding rate of corrosion is discussed, and mention is made of the effect of lightning and other external surges on the corrosion problem.

Experiments on cathodic protection and the inhibiting effect of Portland cement mortars on steel are described.

A-54 Kennedy, T. B., "Tensile Crack Exposure Tests, Report I - Tensile Crack Exposure Test for Reinforced Concrete Beam," Technical Memorandum No. 6-412, Jul 1955, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Eighty-two reinforced beams were made of concrete with a nominal compressive strength of 3500 psi at 28 days age. Air-entrained and nonair-entrained concrete were used. Seventy-four beams were reinforced with rail-steel bars, of which 64 had deformations conforming to ASTM Designation A 305-50T and 10 had old-style deformations. Eight beams were reinforced with billet-steel bars having deformations conforming to ASTM Designation A 305-50T. Coverage over the steel was either 3/4 in. or 2 in. and bars were placed in either bottom or top position when the concrete was placed. Seventy-two beams were stressed from 20,000 to 50,000 psi by third-point loading and in the loaded condition exposed to severe natural weathering at half-tide elevation on the beach at Treat Island, Cobscook Bay, Maine. Ten control specimens were exposed but not loaded.

Evaluation of the test results was based on the condition of the specimens after two winters exposure because of the rapid deterioration of the nonair-entrained concrete beams which constituted the majority of the specimens in the program.

1956

A-55 Swenson, E. G. and Chaly, V., "Basis for Classifying Deleterious Characteristics of Concrete Aggregates Materials," Proceedings, American Concrete Institute, Vol 52, May 1956, pp 987-1002.

Deleterious characteristics of concrete aggregate materials are reviewed and a simplified arrangement for their classification is proposed. This arrangement is based on a recognition of harmful properties rather than on types of materials, thus providing the testing engineer with a more systematic basis for laboratory evaluation of aggregates. Harmful properties that involve chemical action are given the same emphasis as those involving the physical nature of the material. These properties are discussed in relation to the limitations of conventional methods of test and the need for supplementary testing based on petrographic and chemical techniques.

1957

A-56 Mather, K., "Investigation of Deterioration of Concrete, Davis Air Force Base, Muskogee, Oklahoma," Miscellaneous Paper No. 6-236, Oct 1957, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Additions to the facilities at Davis Air Force Base, Muskogee, Oklahoma, were scheduled for construction under the direction of the Tulsa District in the summer of 1957. The contractor had indicated his intention to use natural aggregates from the Grand and Arkansas Rivers in this work. These aggregates were used in constructing pavement at the base in 1942-1943. In May 1957, following a period of abnormal rainfall, it was observed that some of the 1942-43 pavement had developed severe deterioration.

Investigations were made by the Southwestern Division Laboratory that revealed the Grand River gravel to be potentially deleteriously chemically reactive. Examinations of the pavement at the site and tests of samples of concrete, subgrade soil, and water were made by personnel of the Waterways Experiment Station. The inspection showed deterioration to be developing in areas with poor surface and subsurface drainage. The concrete cores were subjected to petrographic examination, X-ray diffraction, and thermal tests. The soil and water samples were tested chemically.

The concrete cores showed evidence of extensive alkali-aggregate reaction, and the deterioration is believed to be the result of deleterious alkali-aggregate reaction and sulfate attack on concrete placed on a heavy clay subgrade. In view of these findings, it was concluded that the decision to use crushed limestone coarse aggregate rather than Grand River gravel was justified. Since the fine aggregate contains small amounts of chalcedonic chert it was recommended that low-alkali type II cement be used.

A-57 Feld, F., "Failures of Concrete Structures," Proceedings, American Concrete Institute, Vol 54, Dec 1957, pp 449-470.

A historical survey of concrete failures of the last half century in the United States; discusses significant examples without attempting to list all failures. Touches on legal aspects from the Code of Hammurabi through English common law with some observations on present code requirements as they

relate to different types of failure. Concrete failures are grouped according to their major causes: design deficiency, drafting and detailing errors, concrete mix, supervision omission, frost protection defects, bearing wall deficiency, foundation deficiency, faulty erection techniques, temperature and shrinkage, secondary stresses, and inadequate formwork.

A-58 Verbeck, G. J. and Klieger, P., "Studies of 'Salt' Scaling of Concrete," Bulletin 150, Publication 485, pp 1-13, 1957, Highway Research Board.

The service record of air-entrained concrete pavements exposed to deicing salts is excellent. However, the mechanism by which deicers cause or accelerate surface scaling of nonair-entrained concrete is unknown. Furthermore, there is an incomplete understanding of why entrained air is beneficial in this regard.

Although field experience indicates that air entrainment is a practical remedy for surface scaling, some laboratory tests indicate that under certain extremely severe conditions entrained air does not give complete protection.

The objective of this study is to provide more information on the effect of type and concentration of deicer, curing condition of concrete, air entrainment, and other variables on the surface scaling of concrete. This information should lead to a better understanding of the effect of these variations and should be of assistance in the establishment of further remedial measures.

1958

A-59 Kennedy, T. B., "Laboratory Testing and the Durability of Concrete," Miscellaneous Paper No. 6-270, Jun 1958, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Concrete structures cannot be constructed and subjected to full-scale tests for durability in a manner analogous to load tests. It therefore is necessary to estimate the durability of concrete structures by combining information gained from a study of service yielded by existing structures, controlled exposure tests of specimens, laboratory simulated-service

tests, and tests and analyses of concrete and concrete materials. None of these sources of information provide a basis for adequately evaluating the effect on durability of workmanship, honesty, and intelligence that may or may not be employed in all stages of the operation from production of concrete materials to maintenance of the completed structure.

Durability of concrete structures is determined by materials, workmanship, design, and exposure. Petrographic examination of aggregates, X-ray diffraction studies of cement, freezing and thawing tests of concrete both in the laboratory and at field exposure stations, and pulse velocity tests of specimens and structures are recommended means of improving knowledge of durability of concrete and concrete structures.

A-60 "The Alkali-Aggregate Reaction in Concrete," Research Report 18-C, 1958, Highway Research Board, National Academy of Sciences, National Research Council.

A resume of field experience, laboratory tests for reactivity of aggregates, and a review of the fundamental research to show the mechanism of the reaction.

A-61 Gewertz, M. W., "Causes and Repair of Deterioration to a California Bridge Due to Corrosion of Reinforcing Steel in a Marine Environment," Part I, Method of Repair, Bulletin 182, pp 1-17, 1958, National Research Council, Highway Research Board.

The California Division of Highways maintains numerous reinforced concrete bridge structures, on some of which the reinforced concrete has deteriorated from varying causes and in varying degrees. This paper discusses a particular phase of this type of deterioration; namely, deterioration of structural parts as a result of buildup of internal corrosion on steel bar reinforcement in a marine atmosphere and the consequent rupture of the surrounding concrete. The paper describes conditions encountered at the San Mateo-Hayward Bridge, a major transbay structure consisting of a 6.76-mile length of reinforced concrete trestle construction, plus a 1,503-ft length of steel truss construction including a vertical lift drawspan.

This structure, acquired by the state in 1951, some 22 years after its construction, now presents the Bridge Division with its most extensive problem of concrete deterioration from the cause previously mentioned. The extent of the deterioration was considered of sufficient magnitude to justify initiation of a research project to determine the cause and possible cure of the condition.

Part I of this paper discusses the history of the structure, character and extent of the deterioration, inspection and estimating procedures prior to repair, repair procedures, basis of contract payment, and costs of repair.

A-62 Halstead, W. J., "Chemical Reactions of Aggregates in Concrete," Special Report 31, 1958, Highway Research Board.

This report approaches the "alkali-aggregate" problem from a practical viewpoint. It is intended to provide information concerning the locations where the reaction has occurred, the laboratory techniques that have been developed to identify potentially reactive aggregates, and recommendations for their use in concrete. Theoretical discussions of the mechanisms of the reaction have been omitted. Instead, emphasis is placed on what has been done and the findings that will most likely be useful to engineers faced with problems of identifying potentially dangerous aggregates or with the necessity for using such aggregates in structures. No attempt has been made to prescribe exact measures that should be taken in any specific instance, inasmuch as no single solution will be applicable to all situations.

A-63 Jeppesen, A., "Durability and Maintenance of Concrete Structures in Danish Railways," Progress Report No. B3, 1958, Committee on Alkali Reactions in Concrete.

Problems of concrete damage, superficial as well as more radical, and deformations in reinforced concrete and concrete structures are studied in regard to maintenance work, causes of such damage, methods applied in maintenance, and construction and maintenance costs of reinforced concrete vs. concrete railway bridges.

A-64 Smith, F. L., "Effect of Aggregate Quality on Resistance of Concrete to Abrasion, Cement and Concrete, Special Technical Publication No. 205, pp 91-106, 1958, American Society for Testing and Materials, Philadelphia, Pa.

Sixty concrete mixes using different combinations of aggregate, combining good quality sand and gravels with poor quality sand and gravels, different sand contents and water-cement ratios, the latter ranging from 0.32 to 0.70, were used to determine their effect on the resistance of concrete to abrasion. Aggregates were selected which represented Los Angeles abrasion losses at 500 revolutions ranging between 12.6 and 39.1 percent. Measure of resistance to abrasion loss was determined by three types of abrasion machines: the Davis steel ball and the dressing wheel abrasion apparatus, which represent the types of wear caused by steel wheels under heavy load, and the Ruemelin shotblast apparatus, which simulates the erosion caused by solids in flowing water.

A-65 Tremper, B., Beaton, J. L., and Stratfull, R. F., "Causes and Repair of Deterioration to a California Bridge Due to Corrosion of Reinforcing Steel in a Marine Environment," Part II, Fundamental Factors Causing Corrosion, Bulletin 182, pp 18-41, 1958, National Research Council, Highway Research Board.

Available construction records show that, judged by present day standards, the water-cement ratio of the concrete in the San Mateo-Hayward Bridge was high for the conditions of exposure. It is evident that the concrete has suffered from sulfate attack to a moderate, but not yet critical, degree. The concrete has relatively high absorption and permeability. However, the concrete shows little outward indication of distress other than severe cracking in the plane of main reinforcing members, accompanied by severe spalling at some locations.

It is evident that rupture and spalling are primarily the result of pressure caused by corrosion products of the reinforcing steel which have characteristics differing from those found on steel subjected to atmospheric corrosion. No evidence could be found that stray currents had produced electrolysis.

Chlorides in samples of the concrete indicate that substantial quantities of sea salts have been absorbed. Characteristically the concentration of salt varies from point to point and for this reason macro galvanic corrosion cells of the differential concentration type have been established. Electrical potentials approaching 0.5 have been measured between points 2 to 10 ft apart. Potential measurements over a systematic grid on the surface of members indicate the existence of numerous, distinct anodic and cathodic areas. The rate of corrosion is determined by the activity of the cell. Variations in average atmospheric humidity at different parts of the bridge are believed to explain variations in the rate of corrosion.

When affected concrete is removed and replaced with new shotcrete, the pattern of cathodic and anodic areas is changed.

Laboratory tests have confirmed the role of salts and moisture in promoting corrosion. Both laboratory and field studies are being continued.

Work on two experimental methods of eliminating or retarding future corrosion is under way at the bridge site. This consists of (a) cathodic protection and (b) the application of a coating impervious to oxygen to the surface of cathodic areas of the deck units.

<u>1959</u>

A-66 Moum, J. and Rosenquist, I. Th., "Sulfate Attack on Concrete in the Oslo Region," <u>Proceedings, American Concrete Institute</u>. Vol 56, Sep 1959, pp 257-264.

In the Oslo region of Norway, alum shales containing small amounts of the unstable iron sulfide, pyrrhotite, produce an unusual form of sulfate attack upon concrete placed in or near these deposits, and cause deterioration if they are used as concrete aggregate. The ground water associated with the alum shales carries ferrous sulfate and produces severe sulfate attack and the precipitation of ferric iron compounds in concrete structures made with normal portland cement. Cements of low tricalcium aluminate content resist the sulfate attack but may be subject to attack by acid solutions produced when the ferrous sulfate is oxidized. Air-entrained concrete appears to be particularly susceptible.

<u>1960</u>

A-67 Roshore, E. C., "Investigation of Performance of Concrete and Concreting Materials Exposed to Natural Weathering," Technical Report No. 6-553, Volumes 1 and 2, Jun 1960 with annual supplements beginning in 1962, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

To assess the durability of concrete and other materials used in concrete construction when exposed to natural weathering, the Corps of Engineers maintains severe-, mild-, moderate-, and nonweathering exposure stations at various locations in the United States. Specimens from actual structures and experimental specimens in which the amounts or kinds of components are varied are exposed until they fail or until testing is completed, whichever occurs first. The specimens are inspected periodically, and tested to determine their dynamic modulus of elasticity and pulse velocity. This report, in two volumes, describes the exposure stations, test methods used, the specimens, and lists test results to date. Volume 1 contains the active investigations, and Volume 2 the completed investigations. These volumes are in loose-leaf form so that new or revised data can be added to Volume 1, and completed studies can be transferred from Volume 1 to Volume 2. A preliminary report was prepared in June 1959, but the first complete edition was issued in June 1960. Revisions will be distributed annually.

A-68 Tyler, I. L., "Long-Time Study of Cement Performance in Concrete, Concrete Exposed to Sea Water and Fresh Water," <u>Proceedings, American Concrete Institute, Journal</u>, Vol 56, No. 9, Mar 1960, pp 825-836.

During 1941 and 1942 four experimental installations of test piling were driven, three in sea water and one in fresh water, for studies of concrete performance. One sea water exposure was in the east mooring basin of Cape Cod Canal, so as to evaluate the effect of exposure in a cold climate. A fresh water exposure in similar climate was constructed at the confluence of Esopus Creek and the Hudson River at Saugerties, N. Y. Two other sea water exposures were in the mild climates of Florida and southern California. Twenty-two of the 27 Long-Time Study cements were used in the three

eastern exposures; seven were used in California. After more than 15 years, significant trends in performance are developing, not all of them along the anticipated lines of the investigation of cement performance but still of much more than casual interest to users of concrete in marine construction.

A-69 Chaiken, B. and Halstead, W. J., "Correlation Between Chemical and Mortar Bar Tests for Potential Alkali Reactivity of Concrete Aggregates," Bulletin 239, pp 24-40, 1960, Highway Research Board.

Certain siliceous constituents of aggregates can react with cement alkalies to cause abnormal expansion and cracking in concrete. The ASTM mortar bar expansion test is generally considered to be the most reliable method available for determining the potential alkali reactivity of such aggregates. Because this test requires considerable time, a quick chemical test was also adopted by the ASTM in order to obtain a rapid evaluation of concrete aggregates. This investigation was made to determine the degree of correlation between the two methods of test.

Fifty-two concrete aggregates were evaluated by means of the rapid chemical test for potential alkali-aggregate reactivity and the results generally showed good correlation with the data obtained in the mortar bar tests. However, the chemical test does not always give reliable results for some aggregates because of the interference of certain carbonates. An empirical division of the chemical tests results is proposed which would serve to isolate those aggregates which may contain such interferences, and thereby indicate the need for further tests.

Some aggregates showed a high degree of reactivity in the chemical test but did not produce excessive mortar bar expansion. An additional empirical division of the chemical test results is suggested which would separate chemically reactive aggregates into two groups. Such a separation would eliminate the need of supplementary mortar bar tests on many reactive aggregates. Chemical test results which fall into one such group are indicative of very highly reactive but not necessarily expansion-producing aggregates. Special mortar bar tests are necessary for such materials.

The general chemical test criteria established by this study for separating reactive from nonreactive aggregates agree fairly well with those proposed by ASTM specifications and the Corps of Engineers. The present ASTM chemical test

method permits two titration procedures for the determination of alkalinity reduction. Neither procedure showed any distinct advantage over the other as a means for evaluating the potential reactivity of aggregates.

1961

A-70 ACI Committee 714, "11-Year Study of Concrete Stave Silo Durability," Proceedings, American Concrete Institute, Journal, Vol 57, No. 7, Jan 1961, pp 797-812.

In 1940, ACI Committee 714 set up a research program to test the adequacy of a proposed ACI standard, "Recommended Practice for the Construction of Concrete Farm Silos." The test consisted of four silos erected on the Ohio Agricultural Experiment Station at Wooster, Ohio. Each of the silos contained dry-tamped and wet-cast staves made from concrete mixes containing three grades of aggregate, three levels of cement content, and two types of cement. In addition to these variables, the interiors of two of the silos were coated with a portland cement "wash-coat" while the other two were left uncoated. The silos were used for storing silage under conditions similar to those found in average farm service.

Periodic visual observations of the conditions of the staves were made during the 11-year test period. Flexural strength and absorption tests of the staves, performed on unexposed staves near the start of the project and also on 11-year old staves removed from the silos, showed good correlation with the visual results. The study showed that to obtain the desired low absorption and high strength values, silo staves must be made from concrete containing good aggregate and moderately high cement content. Proper application of a portland cement wash coat will substantially increase the service life of a quality concrete stave silo.

The tests specified for concrete staves in ACI 714-46 are good yardsticks for measuring the durability of concrete silos in service; however, results of this study indicate that a more restrictive current standard would result in prolonged life of the staves under service conditions.

A-71 "Sulfate-Resistant Concrete: Literature Review," Technical Report No. 6-569, Report 1, May 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

A limited review of the technical literature was made to determine the present state of knowledge concerning: (a) the nature and mechanism of sulfate attack on concrete; (b) methods of minimizing or preventing sulfate attack; and (c) methods of guarding or restoring existing structures affected by sulfate attack. The information contained is summarized in this report to assist in the production of concrete resistant to sulfate attack, or in the preservation or restoration of existing structures.

In general terms, the degree of sulfate attack on a concrete structure is dependent on (a) the type of cement used in the concrete; (b) the quality of the concrete with regard to sulfate resistance; (c) local conditions (for example, sulfate concentration in the soil and ground water); and (d) surface protection given to the concrete.

Before the structure is built, local conditions should be studied to determine the need for using Type II or V cement, or special cements, or for the addition of pozzolans to afford sulfate resistance. If any sulfate attack is expected, the quality of concrete produced will be of paramount importance, regardless of the type of cement used or the admixtures incorporated in the mixture. Surface coatings may be used as an added precaution but cannot be substituted for good-quality concrete. After the structure is in place, surface coatings and adequate drainage are the only means of protecting the concrete from sulfate attack.

A-72 Lyse, I., "Durability of Concrete in Sea Water," Proceedings, American Concrete Institute, Journal, Vol 57, No. 12, Jun 1961, pp 1575-1584.

Paper deals with the durability of concrete when exposed to freezing and thawing in sea water. Extensive experimental investigations have for the past 20 years been carried out at the concrete laboratory of Norway's Institute of Technology, Trondheim, and the most important results from these investigations are reported here.

Among the more important results is that freezing and thawing in sea water is much more detrimental to the durability of the concrete than is the freezing and thawing in fresh water. Furthermore, it is shown that the amount of entrained air necessary for giving the highest resistance of the concrete to frost action in sea water is in the range of 10 to 12 percent, which is more than twice as large as for concrete in fresh water.

A-73 Roshore, E. C., "Durability and Behavior of Prestressed Concrete Beams," Technical Report No. 6-570, Report 1, Jun 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The purpose of this investigation was to develop information on the factors affecting the durability of prestressed (pretensioned) concrete beams, especially the effects of creep in the concrete and pretensioning steel and resulting relaxation of the pretensioning force. Effects of air entrainment in the concrete were also studied.

The investigation consisted essentially of the fabrication and testing of (a) 28 large concrete beams (22 of air-entrained and 6 of nonair-entrained concrete), each containing nine nominal 1/4-in.-diam strands of high-strength steel wire, and (b) 412 small auxiliary specimens of the same concrete without pretensioning strands. Appendix A presents computations used in design of the concrete beams. Some of the beams were tested in the laboratory to determine camber, midspan deflection under flexural loading, length and volume change, and some were exposed to natural weathering at Treat Island, Maine, and St. Augustine, Fla. In Maine they are subjected to freezing and thawing in sea water, and in Florida to the attack of the dissolved salts in warm sea water. The condition, length change, and pulse velocity of the exposed specimens are observed periodically.

The auxiliary specimens were tested in the laboratory to determine the strength, elastic, and plastic properties of the concrete, and are also being subjected to freezing and thawing at the Maine exposure station. The steel strands used to pretension the beams were tested to determine their creep, tensile strength, relaxation, and dynamic modulus of elasticity.

No conclusions are presented since the creep, length change, and exposure tests are still in progress; final results of these tests will be included in a later report. However, test results to date permit the following comparisons of the behavior of air-entrained and nonair-entrained specimens.

As compared with the nonair-entrained concrete beams, the air-entrained beams showed less average camber, about the same average sink-in of the pretensioning strands, less midspan deflection, and withstood greater flexural loads. The large air-entrained beams have withstood two winters of freezing and thawing in sea water whereas the large nonair-entrained beams failed during the first winter. At the time of field exposure, the large nonair-entrained beams had slightly higher initial pulse velocities than the large air-entrained beams.

A-74 Swab, B. H., "Effects of Hydrogen Sulfide on Concrete Structures," Journal of the Sanitary Engineering Division, American Society of Civil Engineers, Vol 87, No. SA5, Sep 1961, p 1.

Disintegration of concrete structures by acids formed from hydrogen sulfide prevails in many areas. In other areas with seemingly similar conditions no disintegration occurs. Many factors must be considered in the design of sewers in which this problem might occur. More research is needed to determine all the causes and the reasons why disintegration does not occur in all localitites under similar conditions.

A-75 Arber, M. G. and Vivian, H. E., "Carbonation as a Means of Inhibiting Sulfate Attack in Mortar and Concrete," Australian Journal of Applied Sciences, Vol 12, No. 3, 1961, pp 330-338.

Compacted mortar specimens (water/cement ratio of 0.5) and permeable mortar specimens (water/cement ratio of 0.25) were subjected to sulfate attack by immersion in 10 percent ammonium sulfate solution after curing in moisture-saturated air at atmospheric temperature for 7 days. All specimens expanded rapidly and disintegrated. Similar specimens, cured in moisture-saturated air and then dried in the atmosphere for various times before being treated with carbon dioxide, were subjected to attack by immersing in 10 percent ammonium sulfate solution. Resistance to sulfate attack after carbonation was greater for permeable specimens than for dense specimens. Undried mortars cannot be carbonated sufficiently to prevent sulfate attack. Lengthening the period of drying before carbonation begins and the period of carbonation increases the resistance to sulfate attack.

A-76 Hadley, D. W., "Alkali Reactivity of Carbonate Rocks - Expansion and Dedolomitization," Proceedings, Highway Research Board, Vol 40, 1961, pp 462-474.

Although unsatisfactory performance of limestone and dolomite aggregates in concrete is relatively rare, certain carbonate rocks have been found to expand rapidly in solutions of the alkali metal hydroxides. These reactive rocks can be

categorized on the basis of mineral composition and texture, all being argillaceous dolomitic limestones. In terms of texture, the rocks are best described as partially dolomitized calcilutites; that is small dolomite crystals scattered through a matrix of extremely fine grained calcite and clay. A simple and rapid laboratory test for the expansive reaction in alkali has been developed.

The expansion of these rocks accompanies the following chemical reaction between the alkalies and the mineral dolomite:

$$CaMg(CO_3)_2 + MOH \rightarrow M_2CO_3 + Mg(OH)_2 + CaCO_3$$

where M stands for K, Na, or Li.

In concrete, the alkali carbonate produced in the dedolomitization reaction will react with hydrated cement products and the alkalies will be regenerated, permitting a continuing reaction with the dolomite.

The rates of both expansion and dedolomitization are functions of the calcite-dolomite ratio and texture of the rock. Although single crystals of dolomite will slowly dedolomitize and expand in alkaline solutions, maximum reaction occurs when calcite and dolomite are present in approximately equal amounts, and when both are extremely fine grained.

1962

A-77 Grieb, W. E., Werner, G., and Woolf, D. O., "Resistance of Concrete Surfaces to Scaling by De-Icing Agents," Bulletin 323, pp 43-62, Jan 1962, National Research Council, Highway Research Board.

This paper reports the results of tests on more than three hundred 16- by 24- by 4-in. slabs subjected to outdoor freezing and thawing with calcium chloride. A previous paper reported results of tests on some of these slabs exposed to 51 cycles of freezing and thawing. These tests were continued to 154 cycles.

Additional tests were made to study the effect of various protective coatings and various admixtures on the scaling of concrete caused by de-icing agents. These tests indicate that surface protective coatings were, in general, of little benefit in preventing scaling.

Some of the admixtures tested were beneficial in preventing scaling. However, the increased resistance to scaling in most cases appears to be related to the air content and the water-cement ratio of the concrete.

The surface protective coatings tested included silicones, latexes, and curing materials. The admixtures included air-entraining agents, fly ashes, silicones, and latexes.

A-78 Klieger, P. and Fountain, S., "A Cooperative Bridge Deck Study," Bulletin 323, pp 23-25, Jan 1962, National Research Council, Highway Research Board.

This cooperative bridge deck study was undertaken in an effort to remedy this lack of adequate information. The participants are the Bureau of Public Roads, a number of state highway departments, and the Portland Cement Association. The study has four major objectives:

1. To determine the extent of deck deterioration in selected areas.

2. To determine the causes of the various types of deterioration.

3. To develop reliable methods, where needed, for preventing deterioration on future construction.

4. To develop methods of retarding deterioration on existing bridges now showing deterioration.

A-79 Abdun-nur, E. A. and Mielenz, R. C., "An Unusual Case of Freezing of Fresh Concrete," Proceedings, American Concrete Institute, Journal, Vol 59, No. 6, Jun 1962, pp 803-813.

An unusual example of freezing of fresh concrete in floor slabs has been observed in the Platteville Elementary School Building, Platteville, Colo., built in the fall of 1957. Initial evidence of distress was numerous, closely spaced bumps in the finished surface of the floors. These protuberances are especially disturbing in areas of tiled floor, where they were first noted.

Detailed examination of the floor slabs, both at the site and by microscopical examination of drilled cores, showed that the upper 1/2 to 1-1/4-in. of the concrete had been frozen before hardening, causing intense fracturing of the near-surface portion and producing bumps over originally frozen lumps of sand and shale incorporated in the concrete. It is concluded that the bumps formed as a result of growth

of ice lenses within and adjacent to the frozen lumps. The irregularities of the floor surfaces have increased progressively with time in areas of concentrated traffic, because of disintegration of the highly fractured near-surface concrete beneath the floor tile under the impact of heavy foot traffic.

1963

A-80 Neville, A. M., "A Study of Deterioration of Structural Concrete Made with High-Alumina Cement," Proceedings, Institution of Civil Engineers (London), Vol 25, Jul 1963, pp 287-324.

A comprehensive study of the subject. Both laboratory research and field observations are surveyed and organized, and a consistent pattern is shown to exist. Restrictions on the use of high-alumina cements in various European countries are noted. Author summarizes results of his study in the form of some 12 conclusions, of which the last, while general, encompasses the whole: Produced under carefully controlled conditions and used under the right conditions, high-alumina cement concrete is a valuable material; but the cement must be used with discretion, and not simply as a rapid hardening cement.

A-81 Hansen, W. C., "Anhydrous Minerals and Inorganic Materials as Sources of Distress in Concrete," Highway Research Record No. 43, pp 1-7, 1963, Highway Research Board.

This report defines the extent of the problems that exist with respect to the deterioration of concrete from reactions involving (a) hydration of partially or completely dehydrated components of the aggregate, and (b) reactions of organic materials associated with aggregates. The first part of this assignment is to theorize as to what compounds could exist in either natural or artificial aggregates in forms in which they might cause distress in concrete by combining with water. This approach applies also to what might be classed by-product aggregates such as cinders and slags.

A-82 Roshore, E. C., "Durability and Behavior of Pretensioned-Prestressed Concrete Beams," Miscellaneous Paper No. 6-611, Dec 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

To develop data on the factors affecting the durability of prestressed (pretensioned) concrete beams, 28 large beams containing pretensioning strands and 412 small companion specimens without pretensioning strands were fabricated. The concrete in 22 of the beams was air-entrained; that in the other 6 was not. Appendix A presents computations used in designing the beams.

Some of the beams were subjected to laboratory tests, which indicated that the air-entrained beams showed less average camber, about the same average sink-in of pretensioning strands, less midspan deflection, and an ability to withstand greater flexural loads than the nonair-entrained beams. Creep tests are still in progress. A number of the auxiliary specimens were also tested in the laboratory to determine the strength, elastic, and plastic properties of the concrete.

The rest of the beams and auxiliary specimens were exposed to natural weathering at stations on the Maine and Florida coasts. In Maine they are being subjected to cyclic freezing in air and thawing in sea water, and in Florida to sulfate attack in warm sea water. At the Maine station the nonair-entrained beams failed during the first winter of exposure, whereas the air-entrained beams remain in good condition after four winters. No significant results of the Florida exposure have been observed to date.

1964

A-83 "Spalled Concrete Traced to Conduit," Engineering News-Record, Jan 16, 1964, p 32.

Because of the cracking phenomenon in concrete structures (caused by galvanic action set up by contact between the reinforcing steel and aluminum conduit) the Public Buildings Service, the U. S. Army Corps of Engineers and the D. C. Building Department have banned the use of aluminum conduit in concrete. One city's housing authority has banned concrete-embedded aluminum since 1961.

This paper also gives some pros and cons on the use of aluminum.

A-84 Concrete Corrosion Due to Sulphates," New Zealand Concrete Construction (Wellington), Vol 8, No. 5, May 12, 1964, pp 91-92.

Sulfate corrosion is a cause of deterioration in some concrete structures. It may occur where concrete is exposed to sulfates in groundwater or seawater, sulfurous fumes, or sulfur compounds derived from sewage. It can also occur if sulfates are present in concrete aggregates or are in close proximity to concrete, particularly if moisture is present.

A-85 Luke, W. I., "Alkali-Carbonate Reaction in Concrete From Chickamauga Dam Powerhouse," Miscellaneous Paper No. 6-659, Jun 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Petrographic examination of eight cores from three concrete areas in the Chickamauga Dam powerhouse indicated that an expansive reaction between dolomitic limestone particles present in the coarse aggregate and alkalies present in the cement paste may be responsible, at least in part, for the difficulty that the TVA has had in holding generating equipment in line. The reaction, involving dedolomitization of certain types of carbonate rock by cement alkalies, has been described by Hadley, and Swenson and Gillot. In this investigation direct evidence that the reaction had taken place was found in thin sections of the concrete. The evidence was supported indirectly by length-change measurements (expansion) of concrete specimens made from the cores and exposed to laboratory conditions conducive to the reaction. Thin-section studies indicated that the concrete from wet and damp areas in the powerhouse had reacted more than that from dry areas, which suggests that the concrete in the wet and damp areas had expanded more than the concrete in the dry areas. However, even though an expansive reaction was evident in the cores, the relative amount of coarse aggregate involved was small when total amount of aggregate is considered. The reaction had not progressed sufficiently to cause the concrete to crack, since no evidence of cracking of any sort was seen either in the cores or in thin sections made from the cores.

A-86 Roshore, E. C., "Durability of Prestressed Concrete Beams," Miscellaneous Paper No. 6-665, Jul 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The durability of pretensioned and posttensioned concrete beams is being studied using laboratory-prepared beam specimens.

A group of beams containing pretensioned strands, some made with air-entrained concrete and others with nonair-entrained concrete, was exposed to natural weathering. Sixteen beams were subjected to freezing in air and thawing in seawater at Treat Island, Maine, and three beams were exposed to sulfate attack in warm seawater on the Florida coast. In Maine the nonair-entrained concrete beams failed during the first winter; the air-entrained beams remain in fair condition after five winters. No significant results have been observed at the Florida exposure.

A group of posttensioned beams, all made with air-entrained concrete, was also exposed in Maine. Four posttensioning systems with either external or flush end anchorages, and 12 types of end-anchorage protection were used. The auxiliary steel reinforcement had a nominal 3/4-in. concrete cover. After two winters of exposure, two of 40 end-anchorage protections have become detached, two have become loose, and several have developed a narrow crack at the bond with the beam. In all of the beams that show evidence of failure portland cement concrete was used to enclose external anchorages.

A-87 Roshore, E. C., "Tensile Crack Exposure Tests; Results of Tests of Reinforced Concrete Beams, 1955-1969," Technical Report No. 6-412, Report 2, Nov 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Two series of reinforced concrete beams were made and exposed to severe natural weathering at Treat Island, Maine.

The first series (Series A), installed in 1951, consisted of 82 reinforced concrete beams. Test variables to be studied were type of concrete (air-entrained versus nonair-entrained), thickness of concrete cover over reinforcing steel (3/4-in. versus 2 in.), type of reinforcing steel (rail steel versus billet steel), type of deformations of the reinforcing steel (ASTM Standard A 305-50T deformations versus old-style deformations), degree of tensile stress in reinforcing steel (0, 20,000, 30,000, 40,000, and 50,000 psi), and position of steel in the concrete beam at the time of casting (top versus bottom).

Results after 12 winters of exposure of the Series A beams indicated that the air-entrained concrete beams were significantly more resistant to weathering than the nonair-entrained beams, and that the beams with reinforcing steel having deformations conforming to ASTM Standard A 305 were more resistant to weathering than those with reinforcing steel having old-style deformations. Test data concerning the other test variables are as yet inconclusive.

The second series of beams (Series B), installed in 1954, consisted of 76 reinforced concrete beams. The test variables to be studied, which were identical with those of Series A, were deformations of reinforcing steel, degree of tensile stress in reinforcing steel, and position of reinforcing steel in the concrete beam at the time of casting.

Results after nine winters of exposure of the Series B beams indicated that more exposure is needed to produce deterioration sufficient to permit clear conclusions relative to the influence of the variables under study on the resistance of the specimens to weathering.

Exposure of both series of beams was continued.

A-88 Mather, B., "Alkali Reactions with Carbonate Rock," Miscellaneous Paper No. 6-682, Nov 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Brief review of research concerned with alkali-aggregate (carbonates) reaction in concretes and effect on durability.

A-89 Mather, B., "Effects of Sea Water on Concrete," Miscellaneous Paper No. 6-690, Dec 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

also

Highway Research Record No. 113, pp 33-40, 1966, National Academy of Sciences, National Research Council, Highway Research Board.

Concrete exposed to sea water wetted by solution of salts, principally sodium chloride and magnesium sulfate, are discussed. Damage to concrete usually results from failure to use good practices in concrete construction and often is the

result of freezing and thawing or wetting and drying as much as or more than the results of effects of sea water as such.

<u>1965</u>

A-90 Ryell, J., "An Unusual Case of Surface Deterioration on a Concrete Bridge Deck," <u>Proceedings, American Concrete Institute</u>, Vol 62, Apr 1965, pp 421-442.

Set-retarded concrete placed in a bridge deck and finished with conventional equipment exhibited a severe surface deterioration in the form of flaking several days after paving.

Similar concrete placed in the approach slab on a granular subgrade did not flake.

Laboratory and field investigations showed that the flaking was due to the formation of a weak plane immediately below the surface of the concrete and was closely connected with the bleeding characteristics of the mix.

The solution was found in reducing the bleeding rate of the concrete by a change in the type of set-retarding admixture.

A-91 Roshore, E. C., "Durability of Prestressed Concrete Beams," <u>Journal, Prestressed Concrete Institute</u>, Vol 10, No. 5, Oct 1965, pp 49-59.

In this investigation on durability, begun in 1957, 16 pretensioned beams were subjected to freezing in air and thawing in sea water at Treat Island, Maine; three pretensioned beams, two of which were yoked together and loaded flexurally until cracked, were exposed to sulfate attack in warm sea water at St. Augustine, Florida; and twenty post-tensioned beams with four different post-tensioning systems and 12 types of end-anchorage protection were exposed at Treat Island.

A-92 "De-Icers and Concrete Scaling," <u>Concrete Construction</u>, Vol 10, No. 11, Nov 1965, pp 415-417.

Reviews the factors that influence the scaling resistance of concrete, among them: air content, curing, concrete age, strength, aggregate soundness, placing and finishing techniques, type of deicer used, and protective treatments.

A-93 Liesche, H. and Paschke, K. H., Concrete in Aggressive Waters, 3rd ed., Veb Verlag Finer Bauwesen, Berlin, 1965.

The third edition of this handbook is considerably enlarged. It deals with the interaction between concrete and aggressive watery solutions leading to physical-chemical disintegration of the concrete. Five chapters discuss and explain: (1) the chemical characteristics of the concrete materials and the interaction of various aggressive chemicals; (2) description and occurrence of waters and solutions aggressive to concrete; (3) their examination and classification; (4) determination of the degrees of aggressiveness, and (5) protective measures. In addition, this book furnishes a reprint of applicable German standards, examples, literature, and a discussion of the Russian norm applicable to the subject.

Chapter 1 is perhaps the best and most important part of the book. It explains in very thorough manner the chemical interactions which occur when various kinds of cement and aggregates come in contact with aggressive chemicals contained in the mixing water or in any other water during its further use. The various types of cement used in Germany are treated separately, but in essence the information and conclusions can also be applied to American practice. Chapters 2 and 3 deal with natural aggressive waters, sea water, sewage, factory waste, sediments, etc. Chapter 4 appears somewhat far fetched but is perhaps of practical value in establishing five degrees of aggressiveness under consideration of both the aggressiveness of the water and the resistance to be expected by the selected type and quality of the concrete. Such an approach, properly designed and applied, may help in the control of our judgment and in the evaluation of the dangers. Chapter 5 deals with the possibilities of protection by selection of certain kinds of cement and aggregates, by attempting high density, low permeability, use of air, admixtures, etc., but includes also paint, hardeners, and other surface treatments. The handbook offers an abundance of information, a good part applicable to American practice.

A-94 Maso, J. C., "Primary Factor in the Damage of Concrete by Freezing," Academy of Science, Comtes Rendus (Paris), Vol 260, No. 13, 1965, pp 3703-3706.

By the use of one set of mortar prisms painted with bituminous compound and another set unpainted, it is shown from the results of freeze-thaw cycles (+20 to -20C) that only the hydrostatic pressures developed during the freezing of the water are responsible for the damage to concrete by the action of frost. Differences between the coefficient of thermal expansion of aggregates (limestone and/or granite) and hydrated cement paste have negligible influence on the disruption.

A-95 Mielenz, R. C., "Diagnosing Concrete Failures," Cement, Lime, and Gravel (London), Vol 40, No. 4-5, 1965, pp 135-142.

An extensive discussion is presented of the examination and analysis of hardened concrete to determine its composition and to reconstruct causes of failure and abnormal behavior in service as a material only rather than from structural factors. Preliminary investigations (visual examination, field tests, sampling for laboratory tests), laboratory tests (physical, petrographic), partial chemical analysis of hardened concrete (determination of cement content, of chemical admixtures and of contaminants), quantitative analysis of concrete by microscopical methods, and determination of mixing water content by testing hardened concrete are the main subjects covered in detail.

1966

A-96 Mather, B., "Symposium on Cracking of Concretes; Cracking Induced by Environmental Effects," Miscellaneous Paper No. 6-796, Mar 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

When concrete cracks as a result of its interaction with its environment and the cracking is an undesirable feature of the history of the concrete, the occurrence represents the consequences of an imperfect choice in selecting the particular concrete that was produced for service in the environment

in which it was used. Six phenomena that bring about environmentally induced cracking are mentioned: expansion due to the use of unsound cement, the alkali-silica reaction, sulfate attack, corrosion of embedded metal, freezing and thawing, and plastic shrinkage. In all of these phenomena, environmentally induced moisture movements are primary participants in the phenomena that may cause cracking. In each case the environmentally induced cracking that these phenomena may produce can be avoided by giving appropriate attention to the properties of the concrete and thus including in the specifications for the work appropriate requirements for materials properties, proportions of the materials, and construction practices, and by insuring strict enforcement of the specification requirements selected.

A-97 Mather, B., "*Factors* Which Influence the Deterioration of Concrete in Dams and Measures for Prevention of Deterioration," Miscellaneous Paper No. 6-845, Oct 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Concrete is said to have deteriorated when it has changed with time so as to have become significantly less satisfactory for serving the purposes for which it was made than had been anticipated. Since all concrete changes with time, the goal is to produce concrete that will not have deteriorated until it is no longer needed. This goal will be achieved when the kinds and degrees of change can be predicted and concrete produced with properties such that the changes remain within the tolerable range. When concrete has deteriorated, it is useful to establish whether this resulted from a failure to include the necessary requirements in the specifications that would have prevented the deterioration or whether it resulted from failure to comply with all of the requirements that were included. Specifications now used by major dam-building agencies require selection of cements, aggregates, admixtures, mixing water, mixture proportions, mixing procedures, placing methods, and curing practices, by criteria that are intended to avoid those selections that are conducive to promoting deterioration. If these are enforced, changes with time will be limited to tolerable amounts.

Deterioration resulting from frost action can be prevented by selecting sound aggregates, ensuring adequate air entrainment, and protecting the concrete against freezing until the freezable water content of the paste has been reduced to tolerable levels by hydration. Deterioration resulting from

chemical reactions of alkalies and soluble silica in the aggregates can be prevented by selection of nonreactive aggregate, by the use of low-alkali cement, or by the use of adequate amounts of an effective pozzolan. Deterioration resulting from sulfate attack can be prevented by appropriately limiting the chemically active aluminate content of the mixture. Deterioration resulting from delayed hydration of free lime or magnesia or both in the cement can be prevented by using cements meeting applicable chemical and autoclave-expansion requirements. Deterioration resulting from expansion of certain kinds of aggregate particles caused by chemical reactions other than those with alkalies can be prevented by selecting aggregates not containing such particles. Deterioration resulting from surface contraction due to drying can be prevented by use of cements and aggregates meeting specification requirements imposed for other reasons, by proper selection of mixture proportions for minimum water content of concrete, and by enforcement of proper curing requirements. Deterioration resulting from solution (leaching) can be prevented by use of concrete of approximately low permeability.

A-98 "Durability of Concrete: Physical Aspects (Supplement to Bibliography No. 20)," Bibliography No. 38, 1966, Bibliography, Highway Research Board.

The original Bibliography No. 20 was published in 1957 and included references on durability of concrete - physical aspects - through 1956. In this supplement, covering 1955-1964, the references have been selected to include primarily those references on durability of concrete in highways. Included are effects of freezing and thawing; scaling and disintegration due to icing and deicing agents; effect of air entrainment; disintegration of concrete due to physical instability of aggregates, such as chert; and testing techniques.

A-99 Hansen, W. C., "Attack on Portland Cement Concrete by Alkali Soils and Waters - A Critical Review," Highway Research Record, No. 113, pp 1-32, 1966, National Academy of Sciences, National Research Council, Highway Research Board.

The literature pertaining to the development of sulfate-resistant portland cement is reviewed. The field and laboratory studies carried out by such organizations as the National

Bureau of Standards, University of Minnesota, Portland Cement Association, Engineering Institute and National Research Council of Canada are reviewed and discussed. The accelerated tests proposed for acceptance and specification purposes are reviewed as are hypotheses advanced to explain the mechanism by which sulfate destroys concrete. Data obtained in accordance with ASTM Designation: C 452-64 are correlated with 18-yr data for concrete beams exposed to sulfate soils in the field at Sacramento, Calif.

A-100 Malisch, W. R., Raecke, D. A., Lott, J. L., Kennedy, T. W., and Kesler, C. E., "Physical Factors Influencing Resistance of Concrete To Deicing Agents," National Cooperative Highway Research Program Report 27, 1966, Highway Research Board.

Studies were made of the effects of various concrete production methods on potentially durable concrete. Variations in the surface porosity, strength, and air-void system produced by different finishing techniques were evaluated for typical air-entrained concretes. Large- and small-scale specimens were cast and effects of period and time of finishing, environmental conditions, and additions or water during finishing were evaluated using surface scaling tests, surface tensile strength tests, and microscopical determination of surface air-void parameters.

The results indicated that the surface mortar air content is lower than the mortar air content within the concrete, but the spacing between the voids is at least as small as the void spacing within the concrete. Thus the efficiency of the air-void system at the surface is not affected by the lower air content. Over-finishing and additions of water during finishing generally had no harmful effects on the surface air-void system, but overfinishing did result in more severe deterioration in surface scaling tests. The addition of moderate amounts of water to the surface immediately after casting, and immediate finishing, did not result in significant decreases in surface durability. Combinations of premature finishing, heat and wind applications, and retarded concretes did not produce "weakened plane" scaling and had differing effects on surface tensile strength. The surface tensile strength did not correlate well with the surface scaling resistance.

These data indicate that adequately air-entrained, properly proportioned concrete may be adversely affected by some

finishing procedures, but this adverse effect is not a result of harmful changes in the air-void system. Thus it appears that field concrete found to have a deficient air void system was probably placed with this deficiency present.

A-101 Prior, M. E., "Abrasion Resistance," Significance of Tests and Properties of Concrete and Concrete-Making Materials, Special Technical Publication No. 169-A, pp 246-260, 1966, American Society for Testing and Materials, Philadelphia, Pa.

This paper discusses the various factors that affect the resistance of concrete surfaces to abrasion. The method studied for testing the resistance to abrasion caused by various types of wear indicate that no one test procedure is satisfactory for evaluating all conditions. ASTM Test for Abrasion Resistance of Concrete (C 418-64 T) provides a standard test procedure for one type of wear, but there are no standard specifications for use as criteria for wear.

A-102 Tuthill, L. H., "Resistance to Chemical Attack," Significance of Tests and Properties of Concrete and Concrete-Making Materials, Special Technical Publication No. 169-A, pp 275-289, 1966, American Society for Testing and Materials, Philadelphia, Pa.

The author discusses the general problem of chemical attack and the means for producing concrete to resist it. The report proceeds with a more detailed discussion of the significant aspects of how these chemical actions damage concrete and what can be done to combat them, and in some cases what tests can be used to measure the degree of attack or the success of corrective measures.

1967

A-103 Buck, A. D. and Mather, B., "Deterioration of Concrete Sidewalks and Curbs," Miscellaneous Paper No. 6-866, Jan 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Twenty-four 4-in.-diam concrete cores, three 6- by 12-in. concrete cylinders, and samples of fine and coarse aggregates were examined to determine the cause of heavy surface scaling which occurred in some of the concrete. Eighteen of the cores came from six locations in the affected area. The locations from which they were taken had been selected in pairs separated by expansion joints to represent concrete in relatively better and in relatively worse condition. The other six cores represented new concrete from another nearby area and from a second nearby area that was in good condition after one winter. The three cylinders represented interior concrete from the fourth floor of a new building in the area.

Air content and cement content determinations, and petrographic examinations, were made on the cores from the affected area. Air content determinations were made on the cores and cylinders from the other areas. These examinations yielded evidence that supported the hypothesis that the deterioration of the affected concrete was caused by freezing and thawing which produced damage because the concrete was not sufficiently air-entrained, and that future damage to similar concrete which was still intact could be expected.

A-104 Roshore, E. C., "Durability and Behavior of Prestressed Concrete Beams; Posttensioned Concrete Investigation Progress to July 1966," Technical Report No. 6-570, Report 2, Mar 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This investigation was concerned with exposure testing of end anchorages and end-anchorage protection on posttensioned beams. The study consisted essentially of the fabrication and testing of 20 air-entrained posttensioned concrete beams and 280 auxiliary specimens. The auxiliary specimens were tested in the laboratory to determine the strength and plastic properties of the mixtures used. The 20 beams were installed at the Treat Island, Maine, exposure station in June 1961, where they are being subjected to freezing and thawing in sea water. After 5 winters of exposure, three of the 40 end-anchorage protections have become detached, one has become loose, and 15 have developed a crack at the bond line with the beam. It is concluded that: (a) concrete cover over reinforcing steel should be greater than 3/4 in. when exposure to sea water is involved; (b) differences among the four methods of end preparation of beams that received portland-cement concrete protection over external anchorages do not seem to be significant in the performance of the anchorage protection;

(c) flush anchorages appear to have been more effectively protected than the external anchorages; and (d) epoxy concrete appears to be superior to portland-cement concrete for end protection.

A-105 Mather, B., "Deterioration of Concrete Sidewalks and Curbs," Miscellaneous Paper No. 6-400. May 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Report discusses probable cause for deterioration, and steps taken to correct them, in curbs and sidewalks constructed in 1960-1961, inspected in 1962.

A-106 Buck, A. D., Mather, B., and Thornton, H. T., Jr., "Investigation of Concrete in Eisenhower and Snell Locks, St. Lawrence Seaway," Technical Report No. 6-784, Jul 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Some concrete in the filling and emptying culverts' walls and elsewhere in Eisenhower Lock has deteriorated, requiring extensive repairs. This type of deterioration has not been noted to any extent at Snell Lock, built at about the same time. The known differences regarding the concrete portions of these locks are: (a) they were built by different contractors; (b) in the Eisenhower concrete, 25 percent by weight of the portland cement was replaced with natural cement. Observations were made in the field; samples were taken from both structures and subjected to a wide variety of tests and examinations; concrete varying in relevant factors was made and tested; relevant literature was studied; views of other workers in concrete technology were considered. From these extensive explorations, it was concluded that the unprecedented severe exposure conditions to which it was subjected before it had matured sufficiently to resist them were at fault. These severe conditions were: saturation of the concrete due to submergence during the navigation season; exposure of the saturated areas to severe freezing on termination of navigation in early winter; and continuation of these conditions, which permitted freezing to progress for several feet. The immaturity of this concrete resulted from use of natural cement which matures slower than portland cement. However, when the Eisenhower and Snell Locks were designed, there were no data indicating that a degree of

maturity greater than that attained by the Eisenhower concrete was required to resist the environmental exposure.

A-107 Mather, B., "Field and Laboratory Studies of the Sulfate Resistance of Concrete," Miscellaneous Paper No. 6-922, Aug 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This paper discusses Corps of Engineers work on developing and understanding sulfate resistant concretes. Variables include tricalcium aluminate concentrations, cement content, and water-cement ratios.

A-108 Mather, B., "Concrete Deterioration," Miscellaneous Paper No. 6-927, Sep 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This paper addresses the objective to produce concrete, for any particular use at lowest initial cost, that will undergo limited and predictable degree of change with time so that it will not be found to have deteriorated until it no longer needs to serve its intended purposes.

A-109 Mather, B., "Deterioration of Concrete in Eisenhower Lock, St. Lawrence Seaway," Miscellaneous Paper No. 6-929, Sep 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This paper compares concrete used in Eisenhower Lock with that used in Snell Lock to ensure that conditions that permitted deterioration at Eisenhower Lock are not repeated.

A-110 Wagner, W. E., "Glen Canyon Dam Diversion Tunnel Outlets," Journal of the Hydraulics Division, Proceedings, American Society of Civil Engineers, Vol 93, No. HY6, Nov 1967, pp 113-134.

The left diversion tunnel outlets operated from March 1963 to July 1965. In this period about 5,700,000 acre-ft of water was released through the outlets at discharges to 29,600 cfs at heads to 360 feet. Extensive abrasion damage to the concrete lining was experienced early in the operation because of foreign material circulating in a hydraulic jump that formed in the tunnel during relatively small releases; however, after abrasive material was flushed from the tunnel, no significant additional damage to the roughened concrete lining was noted during releases of 2,799,000 acre-ft of water at velocities of 135 fps.

Progressive cavitation damage was experienced downstream from the gate slots and at surface irregularities in the conduit steel liners. Offsets protruding into the flow as little as 1/32-in. resulted in cavitation damage to the steel liner.

Precautionary measures are necessary to assure that all abrasive material is removed and kept from entering a hydraulic jump stilling basin. Free jets will develop a surface layer of slower moving water and will entrain air that helps prevent cavitation damage from high-velocity flows over irregular or rough surfaces. Smooth and properly aligned surfaces in fluidways and particularly in regions downstream from gate passages are of critical importance. The use of stainless steel in critical flow regions appears desirable to resist the effects of caviation. Joints in cavitation environments should be avoided.

A-111 "Durability of Concrete Bridge Decks - A Cooperative Study," Report No. T107C, Report 3, 1967, Portland Cement Association.

This report deals with a detailed investigation of 21 bridge decks in California. The bridges were chosen to provide a wide range of factors, including type and severity of deck deterioration, bridge type, span lengths, location, date of construction, and volume of traffic. Part 1 discusses the observed scaling, various types of cracking, and surface spalling, based on the observations contained in Part 2. Suggestions for preventing deterioration on future deck construction are also presented. Part 2 presents the detailed information accumulated during the California investigation. The report contains illustrative photos taken in the field and in the laboratory.

Two important findings of this study are:

1. The transverse cracks observed on slab-on-beam bridges were nearly always associated with the top transverse reinforcing

and are believed to result primarily from excessive volume changes (drying shrinkage and thermal) in combination with the influence of the reinforcing.

2. Uniform distribution of entrained air voids is essential to scale-resistant concrete. The usual criteria concerning air content and average void spacing were found to be inadequate for detection of nonuniform air-void systems.

A-112 Idorn, G. M., "Durability of Concrete Structures in Denmark," Teknisk Forlag A/S, 1967, Copenhagen, Denmark.

A comprehensive discussion and evaluation of a 1952-55 inspection of concrete structures in Denmark followed by some studies of field concrete deterioration in the United States. Typical symptoms of deterioration are described, and the extent to which the features of deterioration can be correlated with the potential causes of deterioration is discussed. Lack of background information on the structures in question was a distinct problem; very little data were available on the manufacture and characteristics of the concrete or on the climatic conditions over the life of the structure.

Macroscopic and microscopic examination of specimens supplemented the field studies. Drilled cores were found preferable to hewn specimens, particularly when the features of cracking were to be studied. Alkali-aggregate reaction, sulfate attack, effects of frost action, shrinkage, and aging are demonstrated by studies of thin sections.

The author diagnoses the deterioration of several structures, based on the investigative procedure followed. He emphasizes, however, that such diagnosis involved a great deal of personal judgment due to lack of basic data on the structures and the conditions to which they were subjected.

A-113 Spellman, D. L. and Ames, W. H., "Factors Affecting Durability of Concrete Surfaces," Highway Research Record No. 196, pp 41-56, 1967, Highway Research Board.

A laboratory research program on abrasion resistance of concrete surfaces, including the development of an impact-type abrasion test for testing of cored specimens, is described. Variables incorporated in this study were slump, finishing,

curing, surface treatments (linseed oil and monomolecular film), and the use of admixtures. Sand with a low mortar strength was substituted for the laboratory stock sand in two tests. In addition to the abrasion tests, hardened concrete specimens were examined for air content and void distribution by the linear traverse method. A brief summary of reports by others on the causes and prevention of concrete wearing suface deterioration is also presented.

The abrasion samples were cored from laboratory slabs constructed to simulate some of the field conditions and other factors encountered in placing, finishing, and curing of concrete bridge decks and pavement. Although the data presented are limited in scope, relative values of "abrasion losses" are established and are indicative of what might be expected in the field.

Test results show that slump, curing, and time of finishing are the most important factors affecting the abrasion resistance of concrete surfaces. Concrete receiving an application of a monomolecular film to retard evaporation during the finishing period showed an increase in abrasion resistance. A two-coat surface treatment of linseed oil, applied when the concrete had partially dried, was found to increase abrasion resistance appreciably regardless of other variables.

1968

A-114 Waugh, W. R., "Deterioration of Concrete in Eisenhower Lock," Civil Engineering (N. Y.), Vol 38, No. 5, May 1968, pp 62-66.

Deterioration of concrete in one lock on the St. Lawrence Seaway while another lock nearby, built under similar specifications, remains sound poses some interesting questions. Water forced into all voids by successive filling and emptying, then freezing during winter dewatering, is a theory. Cracking around the big culverts is being corrected by prestressing tendons anchored in good concrete.

A-115 Echavez, G. and Sanchez, J. L., "Destruction of Concrete In High Velocity Flow Tunnels," Proceedings, RILEM Symposium On The Effects of Repeated Loading of Materials and Structures (Mexico City, 1966), Vol 1, Instituto De Ingenieria, Mexico City, 1968.

The evergrowing claim for bigger hydraulic structures has confronted the engineer with problems which require urgent solution; such is the case of high speed, large diameter tunnels which must be lined with concrete to prevent the erosive action of water. For relatively small structures, the forming, casting and vibration of concrete are not too difficult. However, in large diameter tunnels (over 22 ft) it is quite difficult to have an effective control on the alignment of forms and on the homogeneity of concrete. These two factors seem to affect to a great extent the behavior of the lining. On the other hand, careful control of these details is opposed to the construction program, which in hydraulic jobs normally imposes serious limitations on the contractor.

A-116 Gjorv, O. E., "Durability of Reinforced Concrete Wharves in Norwegian Harbors," Ingeniorforlaget A/S, 1968, Oslo, Norway.

Among the relatively large wharves for heavy traffic, more slender-column reinforced-concrete wharves have been built along the Norwegian seaboard than all of the other types of wharves put together. The method of tremie concreting such slender members (in cross sections of 80 to 100 cm square and lengths of up to 25 cm) has made this particular type of wharf construction so economically favorable. While such wharves and piers have been extensively used in Norwegian harbor construction for more than half a century, this method of construction has been looked on with little confidence in other countries, if it has been considered at all.

This book gives the results of a recent comprehensive field inspection on 219 Norwegian reinforced-concrete wharves of the slender-column type. The overall good condition observed below the low water level, proved that concrete can be successfully placed under water even for reinforced concrete members with relatively small cross sections. The results demonstrate, however, that sulfate-resisting cements should be an even more important precaution for use of tremie concrete in marine construction than for precast concrete, and this is an important factor to be considered also in the colder regions. Even though the deterioration in the tidal zone must be ascribed mainly to frost action, this deterioration was obviously the result of a more complex interaction between several processes. The deterioration of high quality concrete seemed, however, to develop very slowly. Damage due to steel corrosion was only observed above spring high water level, where the most extensive and serious corrosion was found on the deck beams, this despite the fact that the most extensive repairs also had been carried out on these members.

After a detailed presentation of the field observations, the durability of the structures is discussed and evaluated according to the particular exposure and in light of the existing basic knowledge about the different deteriorating mechanisms. Against this background are given improved general principles of structural design and of the construction and maintenance of all reinforced concrete structures exposed to severe marine environments.

A-117 Klieger, P. and Landgren, R., "Performance of Concrete Slabs in Outdoor Exposure," Highway Research Record No. 268, pp 62-79, 1968, Highway Resarch Board.

Performance data are presented for concrete slabs, air-entrained concrete and a few nonair-entrained slabs, cast on grade and elevated above grade that are exposed to the weather in an outdoor exposure test plot. The slabs were also exposed to chemical deicing. Variables considered are (a) curing procedures and curing times, at both normal and elevated temperatures, (b) concrete surface treatments obtained with proprietary chemicals by special finishing techniques, (c) use of admixtures in concrete, (d) the use of various normal-weight and lightweight concrete aggregates, (e) application of different types of chemical deicers, (f) the effects of different depths of cover on corrosion of embedded steel, (g) the use of various cements, (h) the effect of water-cement ratio, and (i) different maximum sizes of coarse aggregates.

A-118 Larson, T. D., Cady, P. D., and Price, J. T., "Review of a Three-Year Bridge Deck Study in Pennsylvania," Highway Research Record No. 226, pp 11-25, 1968, Highway Research Board.

The results of the initial three years of continuing research project on the durability of concrete bridge decks in Pennsylvania are presented. The study involved field surveys of 38 bridge decks comprising 2782 ten-ft long survey units. A total of 154 cores were taken from 34 of the decks. The cores were subjected to detailed laboratory analyses including determination of air-void parameters by linear traverse techniques, water-cement ratio determinations, and petrographic examination. Seven bridge decks were observed during

construction to examine and evaluate the effect of construction practices on durability. Bridge decks were resurveyed annually to establish rates.

The major types of deterioration found were transverse cracking, fracture planes, potholes, and surface mortar deterioration. The primary causes of deterioration were indicated to be materials (aggregates) and workmanship (overfinishing poor quality control with respect to entrained air and water-cement, and improper placement of reinforcement). Recommendations to alleviate the causes of poor performance and suggested areas of needed research are included.

A119 Stewart, C. F. and Neal, B. F., "Factors Affecting the Durability of Concrete Bridge Decks: Phase 1 - Construction Practices," Highway Research Record No. 226, pp 50-68, 1968, Highway Research Board.

Construction history was recorded on 28 concrete bridge deck placements incorporating planned variations in concrete slump, strike-off machine, finishing, texturing, and curing.

The effect of these variations on deck durability is evaluated by comparing recorded construction data with cracking, surface defects, and abrasion and skid-resistance properties of the finished deck. A deck cracking index, a key factor in the evaluation, has been developed.

Comparison of initial and pre-traffic crack surveys shows concrete age to have a significant effect on cracking. Also, the pre-traffic cracking pattern is significantly unlike that found on similar structures after normal traffic usage. Hence, conclusions on the study's objectives are deferred pending a post-traffic survey.

Normal construction problems hampered control of variations and data collection. These problems will probably reduce the study's over-all effectiveness.

A-120 Woods, H., Durability of Concrete Construction, American Concrete Institute Monograph No. 4, American Concrete Institute/The Iowa State University Press, 1968.

This book presents a basic knowledge of the durability and cause of deterioration of concrete. In a format oriented towards the general concrete user, the author discusses the durability of concrete and the effects of both man and nature on concrete and its constituents.

1969

A-121 Mather, B., "Sulfate Soundness, Sulfate Attack and Expansive Cement in Concrete," Miscellaneous Paper No. C-69-8, Jun 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Discusses physical and chemical effects of phenomena associated with formation of hydrated sulfates in concrete, aggregate, paste, and mortar.

A-122 Neville, A. M., "Behavior of Concrete in Saturated and Weak Solutions of Magnesium Sulphate or Calcium Chloride," Journal of Materials, Vol 5, No. 4, Dec 1969, pp 781-816.

The mechanisms of sulfate and chloride attack are discussed with reference to the influence of the concentration of the aggressive solution on the progress and extent of attack. Changes in length, weight, and natural frequency of concrete specimens made with Types I and V cements, with different water-cement ratios, and exposed to weak and saturated solutions of magnesium sulfate and calcium chloride for 1000 days are described. The saturated solutions are shown to be highly corrosive, but the extent and type of damage vary with the factors involved.

A-123 Axon, E. O., Murray, L. T., and Rucker, R. M., "Study of Deterioration in Concrete Bridge Decks," Highway Research Record No. 268, pp 80-89, 1969, National Academy Sciences-National Research Council, Highway Research Board.

Investigation of the problem of bridge deck deterioration in Missouri was initiated in 1959. The study was conducted in several phases, and this paper presents results obtained from a detailed survey of 620 bridge decks and examination and/or tests on 209 partial or full-depth cores.

Most of the discussion in this paper concerns fracture plane and surface mortar deterioration, with major emphasis on the cause and methods of reducing these two types of deterioration. In approaching the study of fracture plane deterioration it was hypothesized that a horizontal plane of

weakness or high water gain was built into bridge decks in the plane of the top reinforcing, and that the cumulative effect of many factors over a period of time changed this plane of weakness into a fracture plane. Data supporting this hypothesis are presented.

Suggestions for preventing or reducing serious deterioration in bridge decks include the following measures: (a) Use and properly place, finish, and cure a low-slump air-entrained concrete; (b) insure that bars in the top mat of reinforcing are the maximum size consistent with sound design practices, and the minimum depth of cover over these bars is approximately 1.5 in.; and (c) re-evaluate the reasons for using continuous-span design in preference to simple-span design.

<u>1970</u>

A-124 Callahan, J. P. "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks," Bulletin 36, pp 64-75, Jan 1970, Tennessee University, Engineer Experiment Station.

Research study to determine if concrete bridge deck durability is significantly affected by externally applied loads or forces such as those resulting from traffic, differential settlement, warping, and volume changes in the concrete. Observations indicated two predominant types of deterioration - scaling of surface mortar, and deep seated disruptions resulting from weakened plane formation at the level of the reinforcing steel. An experimental program was undertaken to evaluate the influence of external loading and stress on either the rate or severity of these two types of deterioration.

A-125 Pirtz, D., Strassburger, A. G., and Mielez, R. C., "Investigation of Deteriorated Concrete Arch Dam," <u>Journal of the Power Division, American Society of Civil Engineers</u>, Vol 96, No. PO1, Jan 1970, pp 23-38.

Investigation of a 40-yr old concrete arch dam is described. Apparent normal weathering processes had caused deterioration to a point where repairs were necessary. Repairs were started but suspicions arose that other destructive processes were at work. A concrete coring program led to inconclusive

results. Sonic testing of the dam along with supplementary coring, and a petrographic examination led to the conclusion the concrete was subjected to: alkli-silica reactions, sulfate attack, and leaching of soluble substances from the cement paste matrix. A concurrent stress analysis indicated a factor of safety less than desirable. This led to the immediate replacement of the dam with a similar structure just downstream. Demolition of the old dam verified that the concrete had indeed deteriorated. This dam illustrated that those agents of deterioration are not always easily recognized even though their affects may have reached an advanced stage during service. It also demonstrated the values of petrographic examination and of the soniscope as a tool for evaluation of concrete, provided it is used in its proper context and with ample supplemental data.

A-126 Narrow, I., "Study of Causes of Pavement Deterioration - Survey of D-Cracking at Air Force Bases," Feb 1970, U. S. Army Corps of Engineers, Ohio River Division Laboratories, Cincinnati, Ohio.

Survey determines extent and severity of D-cracking in concrete pavements at 49 bases in various parts of the nation.

A-127 Callahan, J. P., Lott, J. L., and Kesler, C. E., "Bridge Deck Deterioration and Crack Control," Journal of the Structural Divison, American Society of Civil Engineers, Vol 96, No. ST10, Paper 7579, Oct 1970, pp 2021-2036.

An evaluation is made of bridge deck survey findings and laboratory research data in order to characterize the most common types of bridge deck deterioration. Possible causes are identified from the findings of published bridge deck surveys. The most widely accepted mechanisms of deterioration and related results of research on concrete fracture are described. The thermal incompatibility mechanism and structural cracking mechanism are introduced to explain certain laboratory test results and observed bridge deck deterioration. The use of revibration, nonrusting reinforcement; polymerized concrete, mixes with improved resistance to early cracking, and the adoption of improved methods of mixture quality control and aggregate selection are suggested as possible preventatives.

A-128 Meyer, A. H. and Ledbetter, W. B., "Sulfuric Acid Attack on Concrete Sewer Pipe," Proceedings, American Society of Civil Engineers, Vol 96, No. SA5, Oct 1970, pp 1167-1182.

Research was performed to determine if selected surface treatments would react chemically with the portland cement and increase the resistance of a mortar to sulfuric acid attack. Four parameters were investigated: (1) Portland cement type; (2) water-cement ratio; (3) sulfuric acid concentration; and (4) chemical surface treatment. The laboratory tests did not produce a desired solution for the problem of sulfuric acid attack on portland cement mortar. However, the experience in the laboratory did lead to the following conclusions: (1) Magnesium silicofluoride, sodium silicate, potassium silicate, and sodium alginate do not benefit portland cement mortar resistance to sulfuric acid attack; (2) even weak sulfuric acid solutions caused deterioration of both treated and untreated mortars; (3) varying the constituents of mortar produced from either Type I or Type II cement does not prevent failure due to sulfuric acid attack; and (4) sulfuric acid attack on portland cement mortar is a surface phenomenon and does not affect the structural integrity of the interior of the mortar specimens.

A-129 Larson, T. D., Cady, P. D., Browne, F. P., and Bolling, N. B., "Deicer Scaling Mechanisms in Concrete," Code PB-201 976, Dec 1970, Pennsylvania State University, University Park, Pennsylvania.

Objective was investigation of mechanism by which deicers cause deterioration of concrete, isolating previously proposed mechanisms based on thermal shock and direction of freeze. Deterioration associated with calcium chloride solutions found to be dependent on relative humidity and temperature, leading to observation that it is more aggressive as a deicer than sodium chloride. Effect of direction of freeze found insignificant.

A-130 "Concrete Bridge Deck Durability," Report No. 4, 1970, Synthesis of Highway Practice, National Cooperative Highway Research Program, Highway Research Board.

Bridge deck deterioration continues to be a major maintenance problem. Although the true magnitude and extent of the problem has not been fully determined, indications are that concern is widespread.

The most commonly reported conditions are cracking, scaling, and spalling. Cracking, of itself, is not considered to be serious. Also, scaling can be virtually eliminated by the use of high quality air-entrained concrete, assisted when necessary by periodic linseed oil applications. However, spalling, the most serious defect, has proved to be the most difficult to control.

Spalling, in the main, is caused by the corrosion of reinforcing steel, requiring the presence of moisture and a chloride salt. Cracks provide ready access for moisture and salt to reach the steel, although porous concrete without cracks is also susceptible to moisture and salt intrusion.

Various waterproof barriers protected by a wearing course are currently in vogue as a preventative measure. In addition, greater cover over reinforcing steel, increased efforts at crack control, and less porous concrete are urged as essential improvements.

Meanwhile, research is under way to discover alternate methods for deicing, evaluate coatings for reinforcing steel, consider quality improvements inherent in precast construction, and develop reliable waterproof membranes.

A-131 Hall, J. N. and La Hue, S. P., "Effect of Salt on Reinforced Concrete Highway Bridges and Pavements," Special Report No. 115, pp 115-128, 1970, Snow Removal and Ice Control Research, Highway Research Board.

Considerable research has been undertaken to determine the causes for deterioration of bridge deck concrete. It is generally agreed that surface spalling is the most serious and annoying type of distress found in bridge decks. Several recent research reports indicate that corrosion of reinforcing steel is often a factor in the occurrence of surface spalls. This paper focuses on this relationship and discusses the various factors that may contribute to corrosion of reinforcement.

1971

A-132 Ozol, M. A. and Newlon, H. H., Jr., "Concrete Durability Studies, Case Study Number 3: Severe Scaling of an Interstate Bridge Deck; Potentially Reactive Carbonate Aggregates; Progress Report Number 6: An Example of Bridge Deterioration Promoted by Alkali-Carbonate Reaction," May 1971, Virginia Highway Research Council.

This paper relates studies of 15 interstate bridges in Virginia, with respect to materials and engineering design, differing in lithologies of coarse aggregate. Details aggregate composition, performance of concrete.

A-133 "Unexpected Traffic Volume Cuts Pavement Life," Engineering News-Record, 20 May 1971, p 25.

State of Illinois to replace 250,000 square yards of Dan Ryan Expressway pavement in Chicago. Eight-inch-thick reinforced concrete placed in 1959 and 1962 to be replaced with 10-inch-thick concrete reinforced with 3/4-inch deformed steel bars, over 4-inch crushed stone base. Cracking blamed on traffic loads and deicing chemicals which have aggrevated corrosion of reinforcing steel. Studies in 1957 projected 150,000 vehicles daily in 1971; present load 220,000. While overlaying would serve as only a temporary improvement on the Dan Ryan Expressway, the neighboring Kennedy Expressway, troubled but in better shape, will be refurbished with a 10-inch-thick non-reinforced overlay.

A-134 Haderlie, E. C., "Biodeterioration of Materials in the Sea," The Military Engineer, May-Jun 1971, pp 159-163.

Destructiveness of marine animals and organisms to major and minor marine engineering materials, including concrete, summarized. Concrete described as very strong and durable when properly made, and dense, non-porous concrete made with hard aggregate such as silicious sands and granite gravel is particularly immune to marine deterioration. Poorly made concrete readily attacked by boring clams, particularly tropical. Barnacles attached to concrete piles exert considerable pressure on substrate as their bases grow in diameter and they can erode the concrete surface.

A-135 Hughmanick, R. H., "Highway Chlorides - Menace or Manna?" Public Works, Aug 1971, pp 64-66.

Chlorides used to desnow and deice highways bring problems such as deterioration of concrete surface, pollution of waters in runoffs, destruction of roadside growth. Highway Research Board's Report 91, Effects of Deicing Salts on Water Quality and Biota, defines the scope of the highway pollution problem. Salt-settling basins at roadside found as one possible solution.

A-136 Cady, P. D., Carrier, R. E., Bakr, T., and Theisen, J., "Durability of Bridge Deck Concrete, Part 1: Effect of Construction Practices on Durability," Sep 1971, Pennsylvania State University, University Park, Pennsylvania.

Seven concrete decks observed during construction are studied to evaluate effect of construction practices on durability; each deck then examined annually for five years. Four major types of deterioration observed: surface mortar, transverse cracking, fracture planes, spalling. Deterioration related to seven construction factors: form type, slump, air content, placement time, finishing time, delay in curing, depth of concrete cover.

A-137 Roshore, E. C., "Durability and Behavior of Prestressed Concrete Beams; Laboratory Tests of Weathered Pretensioned Beams," Technical Report No. 6-570, Report 3, Oct 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The work described herein involved laboratory tests which were conducted on four prestressed concrete beams which had been exposed to tidal weathering for a considerable period of time. Two of the beams had been exposed in an unloaded condition at the Treat Island, Maine, severe-weathering-exposure station and the other two had been exposed for nine years in a flexurally loaded condition at the St. Augustine, Florida, mild-weathering-exposure station. The laboratory tests conducted on these beams consisted of the examination and tensile testing of the steel prestressing strands after

removal from the beams and tests for depth of carbonation and chloride penetration in the test beams. The steel prestressing strands were found to be corroded externally for 20 to 100 percent of their length. Internal strand corrosion was generally more extensive than the external corrosion: the corrosion seemed to progress along the center wire of each strand. Only eight of the 25 strand sections tested met the tensile strength and elongation requirements of ASTM Designation: A 416-68. Corrosion on the steel strands at the ends of beams showed that the epoxy pads used as end protection were not effective in protecting the ends of the strands. Depth of carbonation tests indicated that carbonation was not a factor in the corrosion of the steel strands. Depth of chloride penetration tests revealed that sufficient chlorides were present in the test beams to cause corrosion on the prestressing strands. The steel strands taken from the St. Augustine beams were in poorer condition than those from the Treat Island beams. The major cause of strand corrosion in the Treat Island beams was the inadequacy of the epoxy pad end protection and susequent spalling. The major cause of strand corrosion in the St. Augustine beams appeared to be the cracking in the beams which resulted from the initial flexural loading.

A-138 Brown, R. P and Fitzgerald, J. H., "A Practical Approach to Counteracting Corrosion of Bridge Structures," Public Works, Nov 1971, pp 63-66.

Study of mechanisms of corrosion in bridge structures, discussion of concrete deterioration, itemization of protective systems and inspection methods, recommendations for inspection, repair.

A-139 "Bridge Deck Deterioration Study, Part 1: A Comparison of 777 Uncovered Decks," 1971, Kansas State Highway Commission.

The Planning and Development Department studied 777 uncovered bridge decks in a survey revealing that spalling and scaling were the most significant types of deterioration. No cores taken, no laboratory work performed in connection with study. Design and materials data obtained from plans and project construction files.

A-140 Porter, L. C., "Deteriorated Concrete in North Platte River Project Substations," Report No. REC-ERC-71-7, 1971, U. S. Department of the Interior, Bureau of Reclamation, Denver. Colo.

Inspection of several electrical substations of the Bureau of Reclamation shows concrete in various stages of deterioration from severe to slight cracking. Concrete cores obtained from visibly deteriorated foundations at Bridgeport and Sidney, Neb., and Laramie, Wyo., show damage from a variety of causes. Bridge deterioration is attributed principally to fire damage. Sidney concrete is seriously deteriorated, badly cracked, and crumbly. In the absence of complete construction records, inadequate inspection and poor quality workmanship are the suspected causes. Concrete in Laramie Substation is deteriorating from alkali-silica aggregate reaction.

1972

A-141 "Bridge Deck Deterioration," Texas Contractor, Jan 18, 1972, pp 24, 40.

Texas highway department maintenance engineers use unique repair method to seal cracks and retard spalling on concrete bridge decks. Texas Transportation Institute joins in research project centered on 23-year-old I-beam bridge, Bosque River, near Stephenville. Full slab thickness replaced in some sections, in others deck scarified, surface latince and spalled concrete removed to provide good bonding surface for cement grout. Costs put at $1.40 per square foot.

A-142 Flor, L. L. and Keith, W. T., "Corrosion Failures Revealed: Inspection of Cement-Lined Water Mains," Materials Protection and Performance, Mar 1972, pp 11-13.

Reports on corrosion in cement-lined water mains at Helix Irrigation District, La Mesa, California, details where corrosion found, what repairs required.

A-143 Demsey, B. J., "A Programmed Freeze-Thaw Durability Testing Unit for Evaluating Paving Materials," Journal of Materials, Jun 1972, pp 143-147.

Freeze-thaw durability testing unit developed and built which is programmed with quantitative temperature data generated from field studies by specially-developed heat transfer model. Concludes that programmed unit provides means for rational laboratory evaluation of freeze-thaw durability.

A-144 Roshore, E. C.,"Cement Durability Program, Long-Term Field Exposure of Concrete Columns," Technical Report No. C-72-2, 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Fifty-two portland cements were collected from 47 cement mills distributed throughout the United States for the purpose of developing information about the manufacture, composition, and durability of these cements. After an extensive laboratory test program (previously reported), concrete columns were fabricated using these cements, and these columns were exposed at outdoor tidal weathering stations at Treat Island, Me. and St. Augustine, Fla. Variables in the exposures were exposure location, type of cement, and aggregate type. The outdoor exposures were carried on for periods up to 30 years. Concrete columns made with untreated cements exhibited very low resistance to the tidal freezing and thawing at Treat Island. Concrete columns made with treated cements exhibited good to extraordinary durability. The treated cements contained a saponifiable material such as resin, tallow, or oil, and the resultant air-entraining property of these cements accounts for their good durability in the tidal freezing-and-thawing exposure. The durability of concrete columns at Treat Island with respect to the aggregates used is in the following order (maximum to minimum durability): traprock, gravel, or dolomite, limestone. The results of these Treat Island exposures indicate the necessity for providing an appropriate air-void system in concrete which is to be exposed to freezing and thawing while saturated. This air-void system can be provided by the use of an air-entraining agent in the concrete mixture. Concrete columns made with 48 cements (44 untreated cements and 4 treated cements) exhibited satisfactory resistance to tidal weathering at St. Augustine, Fla. Concrete columns made with three cements (two treated cements and one untreated cement) performed unsatisfactorily in the St. Augustine

exposure. These cements had a high tricalcium aluminate (C_3A) content (more than 13 percent), which is believed to be responsible for their poor performance. The St. Augustine exposure indicates the necessity of specifying maximum limits for the tricalcium aluminate content of a cement used in concrete which is to be exposed to a moist high-sulfate environment.

A-145 Rahman, M. A., "Damage to Karnafuli Dam Spillway," Journal of the Hydraulics Division, Proceedings, American Society of Civil Engineers, Vol 98, No. HY12, Dec 1972, pp 2155-2170.

Damage to the spillway chute occurred within three months of initial operation. A model study was commissioned to aid in determining the actual cause and sequence of events leading up to the failure. The model indicated that the vertical force acting on the concrete slab at the toe of the hydraulic jump was barely sufficient to hold that portion of the slab in place at the lower discharges; this of course omitted the effect of pressure fluctuations and surges characteristic of the prototype and applied only to symmetrical operation of the spillway gates. The factor of safety proved insufficient for the prototype. The paper also shows in perspective what can be expected from eductors, under varying conditions of operation, when the underdrainage system terminates in the chute blocks of the stilling basin.

A-146 Batrakov, V. G., "Increasing the Durability of Concrete by Additives of Silicon Organic Polymers," 1972, Bureau of Reclamation, Washington, D. C.

The durability of concrete was studied with additives of silicon organic polymers under the complex action of cyclic freezing and thawing, wetting, and drying, capillary suction and evaporation of salt solutions, and also the prolonged continuous action of an aggressive liquid medium. The physico-mechanical properties of concrete with silicon polymer additives were studied. The physico-chemical aspects of the interaction of silicon-organic polymers of the polyhydrosiloxane and sodium siliconate type with the minerals of portland cement, clinker and cements were investigated.

A-147 Biczok, I., Concrete Corrosion - Concrete Protection, 8th ed., Publishing House of the Hungarian Academy of Sciences, Budapest, 1972.

The problems of protecting concrete against aggressive attack, or of keeping damages to concrete structures within tolerable limits are rather complex. The factors controlling the chemical resistance of concrete are, in spite of a vast volume of research, still little understood. Corrosion phenomena are usually difficult to track down in a maze of interwoven chemical and physical processes. On the other hand, the causes of corrosion cannot be identified and the most economical and technically sound protective measures cannot be selected, unless the chemical, physical, and technological processes involved are completely understood. This is why the sections of this book which are of a textbook rather than a handbook character have proved useful to the practicing engineer.

The aggressive influence of water and soil on concrete, as well as the selection of the most efficient protective measures, are problems best tackled by a cooperation between chemists and engineers. This is why this book analyses both domains in fairly great depth, in order to offer guidance to the chemist, to the design and construction engineer, and to the technologist and contractor, in solving the problems each of them may encounter in his particular field of activity. This book is a comprehensive review of the most important achievements in experimental and applied research on concrete corrosion. Concerning some problems related to the corrosion of concrete, and the appropriate control measures to be selected, conflicting views are still often voiced. Also, there are differences in the methods of investigation. Notwithstanding these obstacles, this book represents an attempt at a self-consistent interpretation of corrosion processes, on which aggreement seems to be reached by scientists in various countries, which can be adopted as a sound foundation in specifying protective measures. Conflicting approaches to certain aspects are traced back to the complex character of corrosion processes open to a wide variety of explanations.

In this revised edition the manner of presentation has changed rather basically. In the earlier editions, protective measures followed (in the same chapter) the theoretical discussions of corrosion caused by the individual aggressive solutions; in the present edition, a separate chapter has been devoted to the theoretical discussion of concrete corrosion (Chapter 4) and another one to concrete protection (Chapter 5). The questions of special interest to scientists,

designers or contractors, respectively, have thus been dealt with in separate, self-contained chapters. This rearrangement has inevitably led to some repetitions, e.g., in the case of the repeated recalling of the importance of density for resistance to various types of damage by exposure.

In order to include recent advances in technology, several important additions have become necessary, e.g., on the latest results in the chemistry of cement, and on the standard specifications and directives promulgated since the last edition. Problems of considerable practical interest, e.g., alkali reaction, the corrosion of road concrete, stacks and cooling towers, not discussed earlier, have also been included.

1973

A-148 Hay, R. E., "Evaluation of the Effect of a Silicone Admixture on the Durability of Concrete," FHWA-RD-73-29, May 1973, Materials Division, Federal Highway Administration, Washington, D. C.

The report presents information on the evaluation of the effect of a silicone admixture, Dow Corning 777B, on the properties of portland cement concrete. The admixture was evaluated for its effect on the freeze-thaw resistance, air content, workability, compressive strength, and permeability of the concrete.

A-149 Hersey, A. T., "Causes of Floor Failures," Proceedings, American Concrete Institute, Journal, Vol 70, No. 6, Jun 1973, pp 426-429.

Poor performance (failures) of concrete floors can usually be attributed to improper construction practices. Various types of failures and their cause are given. Recommendations are offered on the selection of materials and construction practices which will avoid most of the common troubles associated with poor performance of concrete slabs.

A-150 Dallaire, G., "Designing Bridge Decks that Won't Deteriorate," Civil Engineering (N. Y.), American Society of Civil Engineers, Aug 1973, pp 43-48.

Since highway departments began heavily salting pavements a decade ago, thousands of bridge decks have developed surface potholes. And many more bridge decks, though they look okay, are likely to develop spalls soon. Plainly worried about the problem, the Federal Highway Administration has been encouraging state highway departments to membrane waterproof existing decks and to experiment with different deck designs on new bridges. This article focuses on new-deck design.

A-151 Atimtay, E. and Ferguson, P. M., "Early Chloride Corrosion of Reinforced Concrete - A Test Report," Proceedings, American Concrete Institute, Journal, Vol 70, No. 9, Sep 1973, pp 606-613.

Exposure test results of 18 flexural beams and 15 unloaded slabs are reported. The main variables were the depth of clear cover, level of steel stress, presence or absence of flexural cracking, water-cement ratio, bar diameter, and prestressing. It has been found that there is an interaction between the cover and the bar diameter which can be expressed as the c/d_b ratio. This ratio is more meaningful in predicting corrosion resistance than just the clear cover in inches. A higher c/d_b ratio and a lower water-cement ratio proved very effective in improving corrosion protection. Concrete cracking, the level of steel stress, and prestressing made only a relatively small contribution to corrosion deterioration in these tests.

A-152 Walters, J. D., "Alkali-Silica Reaction, A Major Cause of Concrete Deterioration," Proceedings, Engineering Foundation Conference, Sep 1973.

The alkali-silica reaction in concrete must be considered a major cause of the deterioration of concrete in dams. The phenomena often results in a reduction in the strength of the concrete and can result in a reduction in the margin of safety of the dam.

Effective means of reducing, if not eliminating the possibility of the alkali-silica reaction include: the use of cement with an alkali content of less than 0.6 percent expressed as Na_2O; the selection and use of non-reactive aggregates; the use of certain pozzolanic admixtures; and good quality control during construction.

Finally, it is important that the owner maintain active surveillance program instrumentation, periodic inspections, testing and analysis as required to assess the condition and to be apprised of any adverse trends that may develop in a dam afflicted with alkali-silica reactivity.

A-153 Goodpasture, D. W., "Effect of Traffic on Bridge Deck Cracking," Proceedings, American Concrete Institute, Journal, Vol 70, No. 12, Dec 1973, pp 793-794.

A study related to concrete bridge deck deterioration was conducted by the University of Tennessee for two years. This report summarizes the results of that study pertaining to the effect of normal traffic on deck cracking and frequency of vibration. An increase in deck cracking was noted for all six of the bridges subjected to normal traffic for nine months. A significant increase in transverse cracking was noted in the negative moment regions of the bridges. There was little change in the frequency of the fundamental mode of vibration and no correlation between the flexibility of the bridge and the amount of transverse cracking was noted. Other factors, such as construction procedures and construction traffic, seemed to affect the deterioration of the bridge deck to a greater extent than the flexibility of the bridge.

A-154 Mehta, P. K. and Williamson, R. B., "Durability of Cement Concrete in Sulfate Environment," Technical Report No. 7, 1973, University of California, Berkeley.

Sulfate attack phenomenon in cement concrete is reviewed. Summary of test results on 67-year-old massive concrete blocks lying submerged in seawater of the Los Angeles Harbor is presented. Surface deterioration of concrete which was more permeable gave evidence of sulfate attack. Review of some recent field and laboratory studies shows that under certain conditions, even good quality cements made with sulfate resisting type portland cements can be vulnerable to long-time sulfate attack. Problems associated with lack of adequate correlation between the laboratory tests and the field performance of cement concretes exposed to sulfate waters are described, and a new laboratory test method which is quick and reliable is presented. Results are given for five different types of cements tested according to the new method.

A-155 Roberts, J. J., "The Crazing of Concrete," Technical Report No. 42.480, 1973, Cement and Concrete Association (London).

A review is made of previous work on the crazing of concrete and a summary is given of the main recommendations in the literature for reducing crazing. This is followed by a report on the testing of 66 concrete columns erected on an exposure area at Wexham Springs. Most of the columns crazed soon after construction, but this crazing was not always apparent unless tracers were employed. On most of the columns cast with birch ply liners in the formwork it was not possible to detect crazing solely by unaided visual inspection, whereas on most of the columns cast with sealed ply liners the crazing was readily detectable. Columns made with mixes having an aggregate-cement ratio of 6 suffered less severe crazing than those with an aggregate-cement ratio of 3.5. A silicone water-repellent for use with new concrete was the most effective treatment for maintaining the color of the concrete, but the possible long-term effects of the treatment are not known.

A-156 Stratfull, R. F., "Corrosion Autopsy of a Structurally Unsound Bridge Deck," Highway Research Record No. 433, pp 1-11, 1973, Highway Research Board.

An investigation was performed on a 12-year-old salt-contaminated, reinforced concrete bridge deck that had to be replaced because of its deteriorated condition. In this investigation, the electrical half-cell potential measurements and effect of chlorides present seem to be related to some threshold amount that changes the steel from a passive to an active state. Beyond this point, the amount of salt present has little or no effect except as it might influence the area of corrosion involved. The chaining or sounding of the deck to locate delaminated concrete performed the function very well but did not necessarily locate the corroded steel. From the observation of the type of cracking, it appeared that the final mode of distress was concrete fatigue. An investigation of actual concrete cover disclosed that there was reinforcing steel corrosion at depths greater than 3 in. It was determined that estimating the pit depth of steel by visually estimating the thickness of rust is not a very useful inspection technique. In this highly salt-contaminated bridge deck, no relation was found between variations in the chloride content of the concrete and the relative severity of the corrosion of the steel.

1974

A-157 Beaudoin, J. J. and MacInnis, C., "Mechanism of Frost Damage in Hardened Cement Paste," Cement and Concrete Research, Vol 4, No. 3, Mar 1974, pp 139-147.

The results of freezing experiments performed on samples of hardened portland cement-flyash pastes, saturated with benzene and water respectively, are presented. The specimens contained portland cement and flyash in the ratio of 55:45 by weight, and had a water-solids ratio of 0.50. A length change anomaly which occurred in the region of the bulk freezing point of benzene is explained by the hydraulic pressure theory. In discussing their own test results, as well as those of others, the authors deal at some length with thermodynamic considerations of moisture movement as it relates to possible mechanisms of frost action.

A-158 Ben-Yair, M., "Effect of Chlorides on Concrete in Hot and Arid Regions," Cement and Concrete Research, Vol 4, No. 3, May 1974, pp 405-416.

The influence of chlorides on cement and concrete is discussed. It is stressed that chlorides enhance sulfate attack. Severe conditions which accelerate corrosion in hot arid areas are described. Laboratory experiments on the behavior of clinker and normal portland cement immersed in corrosive solutions for a period of eight years are described. A scheme for chloride attack processes is described.

Two of the general conclusions are: (1) the penetration and absorption of chlorides into portland cement is much higher than that of sulfates, and (2) climatic factors have a decisive influence on the character and magnitude of corrosion.

A-159 Ost, B. and Monfore, G. E., "Penetration of Chloride into Concrete," Materials Performance, National Association of Corrosion Engineers, Vol 13, No. 5, Jun 1974, pp 21-24.

Under certain conditions, chlorides from the environment can penetrate into concrete. Examples are concrete bridge decks subjected to deicer salts and concrete structures located in or near sea water. Such penetration is an important factor in corrosion of steel and other embedded metals. Although field structures so exposed have been and are being investigated, laboratory studies were needed for a better understanding of the various factors involved. Measurements of penetration of calcium chloride into various concretes and cement pastes were made and are reported. Reductions in tensile strengths of prestressing wires due to corrosion resulting from such penetration are also reported.

A-160 Grass, L. B. and Koluvek, P., "Deterioration of Concrete Ditch Liners in Saline-Alkali Soil," Journal of the Irrigation and Drainage Division, Proceedings, American Society of Civil Engineers, Vol 100, No. IR4, Dec 1974, pp 477-484.

Irrigation head ditches are normally installed at a slightly higher elevation than the field they serve. Since moisture diffuses toward the highest elevation, evaporation and salt accumulation are greatest in the crest of the earthen berm, where the first indications of damage appear. Continual contact with saline solutions causes the concrete to disintegrate by chemical reactions. As dissolution continues, the concrete mass is physically weakened. Sudden temperature changes, due to water entering the ditch while daytime temperatures are high or temperature differences in a partially filled ditch, create a strain on the weakened concrete mass, and eventually cause it to break. This results in an accelerated chemical attack, and eventually the liner needs replacement.

A-161 "Corrosion and Corrosion Protection," Transportation Research Record No. 500, 1974, Transportation Research Council.

Corrosion - one of the most aggravating problems encountered by maintenance, design, and materials engineers - does not appear to be diminishing. Currently much interest and attention are focused on corrosion of reinforcing steel in bridge decks. This work presents five papers on this topic.

A novel way of protecting the bridge deck reinforcing steel cathodically is the subject of the first paper. Here

the principles of cathodic protection, used effectively by pipeline people, are applied to a bridge deck. The paper describes the construction of such a system on a bridge in California and includes data showing that the installation successfully imposed sufficient potential on the steel to counter corrosion.

The second paper discusses tests to determine what construction techniques and portland cement concrete mix design factors are most beneficial in delaying reinforcing steel corrosion under exposure to de-icing salts. Although tests are not yet complete, preliminary results show that low water-cement ratios (0.40), densification of concrete (98 percent of rodded unit weight), and at least 2 in. (50.8 mm) of concrete cover on the reinforcing steel will significantly reduce corrosion possibilities.

The third paper presents performance data on Kansas bridges, identifies corrosion distress as to source, and recommends preventative measures. This very practical and documentary report also includes similar observations on corrosion of structural steel. The fourth paper describes what specifications have been found necessary to achieve the desired cover depth on New Jersey structures.

Protection of the reinforcing steel by coatings is described in the fifth paper. The studies show that certain epoxy powder formulations applied by electrostatic spray techniques, provide durable coatings that have desirable protective properties but do not adversely affect concrete bonding characteristics.

<u>1975</u>

A-162 Aardt, J. H. P. and Visser, S., "Thaumasite Formation: A Cause of Deterioration of Portland Cement and Related Substances in the Presence of Sulphates," <u>Cement and Concrete Research</u>, Vol 5, No. 3, May 1975, pp 225-232.

The rapid deterioration in a sulfate solution at 5°C of autoclaved mortar made with portland cement and dolomitic aggregate is explained. The presence of thaumasite in such mortars and its preparation are discussed. The importance of this mineral in relation to deterioration of building materials is indicated.

A-163 Chatterji, S. and Samgaard, J. A., "Studies of the Mechanism of Calcium Chloride Attack on Portland Cement Concrete," Nordisk Betong (Malmö), Vol 19, No. 5, May 1975, pp 5-6.

To gain a better understanding of the mechanism of calcium chloride attack on portland cement concrete, some concrete sections were stored in a 30 percent calcium chloride solution at 40°, 20°, and 5°C. Other sections were first stored at 40°C for 14 days, some at 20°C, and others at 5°C. The results show that the aggressiveness of calcium chloride solution decreases with increasing temperature. It is inferred that the breakdown of concrete in a calcium chloride solution is due to some compound formation.

A-164 Manson, J. A., Chen, W. F., Vanderhoff, J. W., Cady, P. D., Kline, D. E., and Blankenhorn, P. R., "Polymer Impregnated Concrete for Highway and Structural Applications," Proceedings, First International Congress on Polymer Concretes, England, 5-7 May 1975, pp 403-408.

This paper describes the methods used and the criteria followed to achieve a 4-in.-deep impregnation of polymer in an existing bridge deck. It also describes some of the preliminary findings on the subsequent durability of the polymer impregnated concrete deck.

A-165 Mather, B., "New Concern Over Alkali-Aggregate Reaction," Miscellaneous Paper C-75-3, May 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

also published in

National Sand and Gravel Association Circular No. 122/National Ready Mixed Concrete Association Publication No. 149, Silver Spring, Md., 20 pp.

There are three reasons why there is new concern over alkali-aggregate reaction: (1) The simple, cheap precaution of specifying "low-alkali cement," and obtaining it at no

increase in price over cement not required to be low-alkali, will no longer be widely available. (2) Aggregates not previously regarded as reactive are being found to have reacted in concrete in old structures and to be associated with significant cracking and damage. (3) Serious early damage to concrete structures has occurred in places where it was previously unknown, especially in north Germany. This justifies a re-examination of the state of knowledge and the state of the use of knowledge in this area.

A-166 Denson, R. H. and Buck, A. D., "Tests of Deteriorated Concrete Blocks from Fort Dix, N. J.," Miscellaneous Paper C-75-8, Jun 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Deteriorated and nondeteriorated concrete blocks were tested to determine the mechanism that caused some of the blocks to have exterior face deterioration. Freezing and thawing tests were performed on protected and unprotected specimens at various moisture conditions. Petrographic examinations were performed to determine the quality of aggregate and paste. Frost action, at a moisture content above a critical level, was found to be the mechanism responsible for the deterioration.

A-167 Diamond, S., "Review of Alkali-Silica Reaction and Expansion Mechanisms. 1. Alkalies in Cements and in Concrete Pore Solutions," Cement and Concrete Research, Vol 5, No. 4, Jul 1975, pp 329-345.

Current concern with alkali silica reactions is due to rising alkali contents of cements, changed concrete technology, and necessity of employing marginal aggregates in many areas, as well as to new reports of field damage coming to light. A brief overall view of the physicochemical basis for alkali-silica reactions is given.

The reaction is primarily one of hydroxide ions rather than alkali cations; nevertheless the latter are of critical importance. Alaklies in cement are found primarily as alkali sulfates or as solid solution substituents in calcium aluminate or in belite. The rates at which these reach the pore solution phase are discussed, and data indicating that

concentrations as high as 0.7 molar may be attained in a month or so and maintained indefinitely are discussed.

The relationship between alkali cation concentration and hydroxide ion concentrations are explored, and after a few days of hydration, published data indicate that the two are substantially equivalent. Thus reacting pore solutions may have hydroxyl ion concentrations of the order of 0.7 molar, more than 15 times that of pure saturated calcium hydroxide solutions.

A-168 Vekey, R. C. and De Majumdar, A. J., "Durability of Cement Pastes Modified by Polymer Dispersions," Materials and Structures, Research and Testing (Paris), Vol 8, No. 46, Jul-Aug 1975, pp 315-321.

The time-dependence of some of the properties of portland cement pastes modified by several polymer dispersions has been investigated up to one year under two curing conditions: (a) in air of 65 percent relative humidity at 20°C, and (b) immersed in water at 20°C. Five different classes of polymer have been tried so far: polyvinyl acetates, polyvinyl propionates, butadiene styrenes, polyvinylidene dichlorides, and acrylics. Two or more examples of each type of polymer have been incorporated into cement to produce pastes with a polymer-to-cement ratio of 0.1 and water-to-cement ratios of 0.3 and 0.5.

The density and elastic properties of the pastes have been measured nondestructively and strength values have been determined using a universal testing machine. Attempts have been made to correlate the results of this comparative study with data on the reactivity of the polymers towards alkalis.

A-169 "Chemical Attack on Hardened Concrete," Concrete Construction, Vol 20, No. 8, Aug 1975, pp 328-331, 333, and 350.

Properly made concrete is inherently a rugged, durable material. There are, however, many physical and chemical forces in the environment which can contribute to its deterioration. This article points out some of the conditions that lead to chemical attack on hardened concrete and suggests some precautionary measures to reduce or avoid deterioration. Emphasis is placed on corrosive materials most frequently

encountered. A table on substances that attack concrete and methods for preventing damage is included with the article.

A-170 Mehta, P. K. and Haynes, H. H., "Durability of Concrete in Seawater," Journal of the Structural Division, Proceedings, American Society of Civil Engineers, Vol 101, No. ST8, Aug 1975, pp 1679-1686.

Concrete submerged for 67 years in seawater has shown that low permeability concrete is highly durable to sulfate attack; however, more permeable concrete is susceptible to sulfate attack. Large concrete blocks were retrieved off the Los Angeles Harbor breakwater. The concrete blocks which were retrieved were part of a test program initiated by the Corps of Engineers in 1905. Cores were tested for compressive strength and material deterioration to determine if the concrete was attacked by seawater. Results from other reports of sulfate attack on concrete are summarized. It is concluded that for long-time durability of concrete exposed to seawater, a reduced permeability and reduced alkalinity of concrete appear to be as important as low 3 $CaAl_2O_3$ content of cement.

A-171 Riley, O., "The Decade of the Deck," Proceedings, American Concrete Institute, Journal, Vol 72, No. 12, Dec 1975, pp 704-708.

From 1961 to 1974 a widespread and in-depth research and development effort aimed at improving the durability of concrete bridge decks was made. That effort was notably successful in that it culminated in three consensus reports on the causes and cures of that single most serious bridge maintenance problem. The principal cause was found to be the chloride induced corrosion of reinforcing steel. Beneficial change has been effected by increasing the cover over the reinforcement and by concrete quality control procedures that minimize the tendency toward cracking and that reduce permeability.

A-172 Amsler, D. E., Chamberlin, W. P. and Jaqueway, J. K., "Investigation of Cracking of Slag Aggregate Concrete Pavement, Special Report No. 34, 1975, Engineering Research and Development Bureau, New York State Department of Highways, State Campus, Albany, N. Y.

The frequency of cracking in some western New York pavements containing blast furnace slag coarse aggregate and in others containing other coarse aggregates was investigated. Cracking in slag-aggregate pavements was found to be seven times more frequent than in pavements containing other aggregates. No differences were found in riding quality and service life, but slag-aggregate pavements exhibited a higher level of skid resistance.

A-173 Beifer, O. and Beisland, L., "Erosion in Concrete Pipes Due to High Water Velocities," CBI Report No. 7523, 1975, Swedish Cement and Concrete Research Institute, Stockholm.

According to current codes for sewerage pipes, the water velocity in concrete pipes shall not exceed 4 m/s. If the water velocity is higher, it is specified that a material of greater resistance to mechanical wear must be used.

In connection with the review of codes, the Swedish Cement and Concrete Research Institute investigated the validity of the regulations for modern concrete pipes. The results show that the influence of water velocity on mechanical erosion is usually low, and that concrete pipes in this field of application have a life expectancy that is comparable to other materials.

A-174 Borge, O. E., Paxton, J. A., and Kaden, R. A., "Durability of Vacuum Saturated Concrete and Grout," <u>American Concrete Institute Publication SP-47</u>, Paper No. SP 47-5, pp 89-99, 1975.

This paper presents a durability study for concretes and grout with varying air contents which were subjected to both vacuum saturation and freezing and thawing. This adverse condition might simulate years of natural weathering and thus provided the designers with useful information. The investigation proved that air-entrained concrete had better durability than nonair-entrained concrete regardless of the degree of saturation. In conclusion, sufficient internal void system (air content) is essential for good durability.

A-175 Browne, F. P. and Cady, P. D., "Deicer Scaling Mechanisms in Concrete," American Concrete Institute Publication SP-47, Paper No. Sp 47-6, pp 101-119, 1975.

Three experiments were conducted to study the characteristics of the two primary deicer scaling mechanisms in concrete: 1) a hydraulic pressure mechanism, which is strongly dependent upon the degree of saturation and the deicer gradient, and only occurs under freeze-thaw conditions, and 2) a chemical mechanism, which operates between concrete and concentrated calcium chloride solutions. These two mechanisms are completely independent of one another.

The experiments conducted showed: 1) the absorption of deicers by concrete is directly related to the scaling rate under freeze-thaw conditions; 2) the deicer content in freeze-thaw cycled mortar specimens decreased with increasing depth; and 3) concentrated calcium chloride solutions chemically react with concrete, causing deterioration. The mechanisms presented in the paper serve to explain most of the previous observations which have been made of deicer scaling.

A-176 Buck, A. D., "Control of Reactive Carbonate Rocks in Concrete," Technical Report C-75-3, 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The effects of using reactive carbonate rocks as concrete aggregates were evaluated in a laboratory investigation. Three reactive carbonate rocks, each producing a different manifestation of the alkali-carbonate rock reaction in concrete, were each used at three dilution levels, one with low-alkali and two with high-alkali portland cements, to make concrete specimens that were tested for length changes for three years in a moist environment, and for compressive and tensile strengths to one year. Limited testing for compressive strength was extended to three years. A carbonate rock and a granite gneiss were also used as coarse aggregates in other concrete mixtures to serve as controls. The same carbonate rock was used as fine aggregate in all the concrete mixtures except the three that contained gneiss coarse and fine aggregates. In addition, the expansion of samples of the reactive rocks was measured in one N sodium hydroxide solution. Petrographic examinations and examinations with a scanning electron microscope were made of rock and concrete samples. The detection procedure and control criteria of Appendix C

of the Standard Practice for Concrete for potentially reactive carbonate rocks intended for use as concrete aggregates were considered for validity in view of the laboratory results. Laboratory results are included in the report.

A-177 Carrier, R. E. and Cady, P. D., "Factors Affecting the Durability of Concrete Bridge Decks," American Concrete Institute Publication SP-47, Paper No. SP 47-7, pp 121-168, 1975.

A survey of 249 four-year-old Pennsylvania bridge decks was conducted for two purposes: To determine the condition of the decks with regard to the extent and severity of their deterioration, and to provide insight into the relative importance of those factors, or combination of factors, which cause deterioration.

The overall condition of the decks was somewhat worse than anticipated. It was found that 22 percent of all decks had already developed fracture planes and/or spalls, totalling 1948 sq ft in area. Three of these decks, each with very shallow reinforcing steel, accounted for 84 percent of this area. Of the three principal forms of cracks observed (transverse, longitudinal, and diagonal), transverse cracks were the most prevalent, followed by longitudinal cracks, which were confined almost exclusively to decks with adjacent box beam superstructures. Diagonal cracks were found largely on skewed decks.

Surface mortar deterioration (SMD) was comprised primarily of wear, but also included disintegration due to weathering of weak mortar. Ninety-five percent of the decks observed exhibited SMD to varying degrees, yielding a total area of 266,800 sq ft. Although high average daily traffic (ADT) usually caused more wear, some bridges with no SMD had ADT coun s of over 10,000 and others had deteriorated and non-deteriorated spans adjacent to one another indicating that it is quite possible to build wear resistant bridge decks.

The data were analyzed using a computer statistical technique which resulted in three simple tree diagrams illustrating the interaction of causes and their interrelationships with deterioration. These data analyses pointed repeatedly to variations in construction practices as a major cause of the differences in deck deterioration. Stay-in-place (SIP) metal corrugated forms were shown to sigificantly reduce cracks, but are associated with slight increases in surface wear. However, many SIP formed decks with high traffic volumes showed little wear, indicating that if special

attention is given to the quality of surface concrete, their use can be beneficial. A table is presented wherein the approximate relative importance of the causes of various types of deterioration are indicated.

The recommendations include that depth of reinforcing steel in bridge decks be made a basis-of-payment item, similar to the slab-thickness basis for highway pavements.

A-178 DePuy, G. W., "Freeze-Thaw and Acid Resistance of Polymer-Impregnated Concrete," American Concrete Institute Publication SP-47, Paper No. SP 47-11, pp 233-257, 1975.

The developmental program for concrete-polymer materials has shown polymer-impregnated concrete to have significantly improved durability and structural properties as compared with conventional concrete. Laboratory tests show PIC outlasts conventional air-entrained concrete more than 10 times as long in the Bureau's freeze-thaw test and two or more times as long in exposure to acid. Acid resistance can be further increased by doubly coating the specimen with polymer to improve surface sealing. The Bureau tests are customarily evaluated on a weight loss basis and other criteria would be helpful to evaluate durability and to shorten test times. A series of tests were performed to measure compressive and tensile strength, dynamic modulus of elasticity, length change, ultrasonic pulse velocity, and weight loss of specimens during the course of the tests.

A-179 Fagerlund, G., "The Significance of Critical Degrees of Saturation at Freezing of Porous and Brittle Materials," American Concrete Institute Publication SP 47, Paper No. SP 47-2, pp 13-45, 1975.

The paper treats the problem "Frost Resistance" as a general problem for all porous materials. The basis is the undeniable fact that well defined critical degrees of saturation exist for all porous materials.

1st part - The difference between the new way of defining critical degree of saturation (as a materials constant) and the usual way (as functions of a combination of properties of material and environment) is discussed. Method of determination is shown and discussed.

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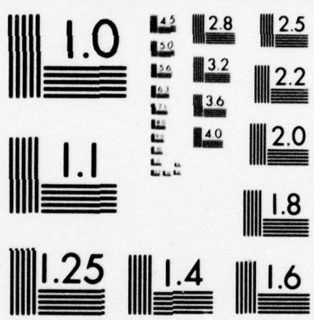

MICROCOPY RESOLUTION TEST CHART
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2nd part - Possible definitions of moisture conditions are provided.

3rd part - By comparison of the critical degree of saturation and the actual reached in practice the frost resistance can be expressed by a plain figure which makes a rational choice of material possible. The method is exemplified. A method of determination of the actual water content is shown. Hypotheses are put forward as regards frost resistance of layered structures or particle composites and frost resistance at use of thawing salts.

4th part - On basis of the hydraulic pressure theory, connections between materials properties and critical degree of saturation are derived. Measurements of amount of ice formed, rate of ice formation and length-changes together with estimations on temperature-permeability relations show the reasonableness of the hydraulic pressure theory. Connections between pore properties and actual degree of saturation are discussed.

A-180 Graham, J. R. and Backstrom, J. E., "Influence of Hot Saline and Distilled Waters on Concrete," American Concrete Institute Publication SP-47, Paper No. SP 47-15, pp 325-341, 1975.

The Bureau of Reclamation (BR) consummated an aggreement with the Office of Saline Water (OSW) to ascertain the feasibility of using concrete in the construction of desalination plants. Concrete and related materials were subjected to flowing brine at temperatures to 290 F (143 C), brine concentrations to 175,000 ppm TDS, and distilled water to 350 F (177 C). Corrosion rates of reinforcing steel were determined, as were thermal gradients across a reinforced wall panel. It was concluded that the concrete tested could be used in brine environments to 250 F (121 C), but not in distilled water environments at any temperature above ambient. Steel corrosion was insignificant.

A-181 Keyser, J. H. and Kushner, M., "Long-Term Freeze-Thaw Durability of Concrete in Catch Basins, Sidewalks, and Pavement Slabs," American Concrete Institute Publication SP-47, Paper No. SP 47-9, pp 191-209, 1975.

The City of Montreal has approximately 65,000 catch basins, 1639 miles of concrete sidewalk, and 979 miles of concrete pavement. The paper gives the history of their long-term freeze-thaw durability.

The first part of the paper deals with catch basins. An information sheet was prepared to describe all possible defects. An examination of the 325 defective units revealed that 90 percent of defects were in the upper three elements, and 57 percent of these, were deteriorated due to frost action. An inspection of the manufacturing process had shown that in the manufacture of dry cast catch basin elements (a) the sequence for adding of admixtures must be controlled (b) a practical test method is needed to determine the air content of no slump fresh concrete (c) the yield of the manufacturer's recommended dosage of air-entraining agent must be verified.

In the second part, the authors show that the sidewalk scaling problem was solved by applying research findings, revising specifications and by implementing a rigid quality control system. During concreting, each truckload of concrete is tested for air content.

The third part of the paper gives the results of an evaluation of long-term variation of the strength of 93 concrete pavement bases. The study revealed that the strength increases at least 15 percent the first year and is expected to increase on the average by as much as 36 percent at the end of 10 years. However the gain in strength is independent of the initial strength and may vary within a wide range.

A-182 Mehta, P. K. and Polivka, M., "Sulfate Resistance of Expansive Cement Concretes," American Concrete Institute Publication SP-47, Paper No. SP 47-17, pp 367-373, 1975.

The results of a test program are reported in which uniaxially restrained, air-entrained concrete prisms made with shrinkage-compensating Types K, M, and S cements were immersed in sulfate solutions after 14 days of water curing. The control concrete was made with a zero - C_3A Type V portland cement. The degree of attack was evaluated by determining the relative expansion and surface spalling behavior of the concrete, and by X-ray diffraction analyses of the damaged mortars. Theoretical computations as well as the experimental results show that the resistance to sulfates of an expansive cement is related to the amount of Al_2O_3 available for sulfate attack. The greatest surface deterioration due to sulfate

exposure was obtained for the Type S cement concrete, while greatest expansions were registered for the Type M cement concrete. The Type K cement concrete was found similar in behavior to the concrete made with Type V portland cement. Both the Type K expansive cement and the Type V portland cement concretes exhibited insignificant expansions and no surface deterioration.

A-183 Polivka, M., Mehta, P. K., and Baker, J. A., "Freeze-Thaw Durability of Shrinkage-Compensating Cement Concrete," American Concrete Institute Publication SP-47, Paper No. SP 47-4, pp 79-87, 1975.

Reported are the results of a study of the effect of freezing and thawing on the durability of air-entrained shrinkage-compensating concretes made with Type K, M. and S expansive cements. The tests were performed on uniaxially restrained prisms which were water-cured for 14 days and then subjected to 300 cycles of freezing and thawing. The durability of the concretes was evaluated by determining the loss in weight of the specimens during the freeze-thaw test. Results were compared to the durability of a similar concrete made with a Type II portland cement. Since the hydration product of expansive cements contains a considerable quantity of ettringite, the effect of freezing and thawing on the stability of the microstructure of ettringite was evaluated by X-ray diffraction analysis.

Results of this investigation indicate that the freeze-thaw resistance of air-entrained shrinkage-compensating cement concretes was similar to that of the corresponding concrete made with portland cement. Exposure to the 300 cycles of freezing and thawing caused only scaling on the surfaces and along the edges of the test prisms with no visible cracking or spalling. The X-ray diffraction patterns taken before and after the freeze-thaw exposure of ettringite indicate no alteration of this material by the freezing action.

A-184 Porter, L. C., "Some Surface Treatments Increase Concrete Durability," American Concrete Institute Publication SP-47, Paper No. SP 47-10, pp 211-232, 1975.

The Bureau of Reclamation's freezing and thawing and outdoor exposure tests of coated and plain concrete show pigmented epoxies to provide greatest protection against concrete deterioration while retaining a pleasing appearance. Latexes, neoprene, synthetic rubber, and some wall-seal epoxies are beneficial, but lack lasting aesthetic value under certain exposure. Tests consisted of freezing and thawing, and outdoor exposure of laboratory fabricated cylinders and prisms. Environments were freezing and thawing in water, freezing by refrigerated air and immersing in water, freezing by chilled air while partially submerged, and weathering outdoors. Accelerated tests help to evaluate protective coatings. However, protection varies under different exposures and coating selection must correlate protection provided with anticipated service exposure.

A-185 Powers, T. C., "Freezing Effects in Concrete," <u>American Concrete Institute Publication SP-47</u>, Paper No. SP 47-1, pp 1-11, 1975.

Theories as to the mechanism of freezing and thawing damage in concrete have been advanced for more than 40 years. The author discusses the evolution of these theories for cement paste, aggregate and the overall concrete. Since the author was prominent in the development of many of the theories his current views of the mechanism of freezing and thawing in concrete are of unique interest.

A-186 Reading, T. J., "Combating Sulfate Attack in Corps of Engineers Concrete Construction," <u>American Concrete Institute Publication SP-47</u>, Paper No. SP 47-16, pp 343-366, 1975.

The six Missouri River dams constructed by the Corps of Engineers are in a region where the ground water has a high sulfate content. The concentration is highest at Ft. Peck, Oahe, and Big Bend.

The problem was recognized at the time of construction of Ft. Peck Dam in the mid-30's, and this is perhaps the first major project in the U. S. where a sulfate resistant cement was specified. Since that time, the Corps has further tightened its cement specifications in areas where the ground water is high in sulfates.

A detailed investigation has been made into the condition of the concrete at Ft. Peck. This included condition surveys, as well as tests on ground water, deposits, and concrete cores.

Most of the Ft. Peck studies were carried out in the late 50's, when the concrete was found to be in surprisingly good condition considering the severe exposure. The overall condition of this concrete is still apparently very good, although a few local areas of fairly severe deterioration have developed which required repair.

An up-to-date evaluation of the condition of the Ft. Peck concrete is advisable.

A-187 Schroder, H. T., Hallauer, O., and Scholz, W., "Durability of Various Types of Concrete in Sea Water and in Sulfate-Containing Water," Heft 252, 1975, Deutscher Ausschuss für Stahlbeton, Berlin.

To establish characteristic values for an economical composition of concrete acted upon by sea water of sulfate-bearing water, comprehensive exposure tests have been carried out since 1955 at the island of Borkum. Specimens have been completely submerged in the sea water and exposed to tide cycles. Other specimens have been kept in sulfate water in Dortmund-Hörde, and null-test specimens have been exposed to sewage water at Münster.

This report documents the composition, manufacture, and curing of the concretes and the tests with fresh and hardened concrete before exposure. It then describes the execution of the exposure tests and the analysis of the results after 3, 5, 10, and 15 years. The degradations are evaluated. Finally, conclusions are drawn for the building practice.

A-188 Seki, H., "Deterioration of Concrete of Coastal Structures in Japan," American Concrete Institute, Publication SP-47, Paper No. SP 47-13, pp 293-303, 1975.

This paper discusses the degree and rate of deterioration of plain concrete structures resulting from field observations and experimental work. Structures investigated were sea walls and wharfs which have been exposed to sea water and sea breeze for approximately 15 to 40 years.

Field investigation was carried out with such methods as visual surface observation, Schmidt hammer (compressive strength) and ultrasonic method (pulse velocity). Cores were taken from upper layers of various concrete structures. Laboratory tests of these cores were as follows: specific weight, water absorption, average depth of neutralization, salt content, compressive strength, and estimation of mix proportions by chemical analysis of finely crushed concrete.

Based on the surface observation of plain structures, the degree and rate of deterioration was evaluated. The main factor for visible deterioration of concrete might be concerned with quality control of concrete at the time of casting, vibrating, and curing. Furthermore, one example of erosion of concrete attacked chemically under acid water (pH 3-7) was introduced.

Depth of neutralization of concrete was 0.1 cm to 3.7 cm. There was no relationship between neutralization and age of concrete mainly because of differences in the quality of the concrete. The concrete contained larger amount of salt than estimated. Test data showed salt content of 0.05 to 0.50 percent. It is believed that salt content in concrete causes corrosion of reinforcing bars embedded in reinforced concrete. Test results of compressive strength for structures exposed to maritime environments indicated approximately 300 kgf/cm^2. On the contrary, it was estimated that some structures used for 20 years had compressive strength of less than 150 kgf/cm^2. Water-cement ratio calculated from chemical analysis of mix proportioning ranged from 50 to 150 percent by weight. Based on these test results, deterioration of concrete was classified into three classes in each test item according to the standard of evaluation proposed.

A-189 Stratfull, R. F., Jurkovich, W. J., and Spellman, D. L., "Corrosion Testing of Bridge Decks," Transportation Research Record No. 539, pp 50-59, 1975, Transportation Research Board.

When the corrosive half-cell potentials on a bridge deck exceed about 10 percent or when corrosion-caused delamination exceeds about one percent of the deck area, a chloride analysis generally would not be required because the chloride content is already too great. For the average depth of reinforcing steel, the quantity of chloride apparently needed to cause corrosion was statistically related to the maximum amount at the 95 percent confidence limits of 1.0 lb/yd^3 (0.59 kg/m^3). The accuracy of chloride determinations was about equal whether

the concrete was drilled or cored. Although the half-cell potential of -0.35 volts to the saturated copper-copper sulfate half-cell (CSE) is indicative of active corrosion, an equipotential contour map is the most reliable means for evaluating the corrosion activity of steel in concrete. After repair of concrete delaminations, the percentage of corrosive potentials decreased by about 50 percent.Repairing concrete delaminations does not prevent or necessarily control corrosion at other locations.

A-190 Vuorinen, J., "Studies on Durability of Concrete in Hydraulic Structures," Nordisk Betong (Malmö), No. 2, 1975, pp 21-28.

In connection with a condition survey concerning concrete in hydraulic structures in Finland, core samples were drilled from concrete in fifteen different structures selected for detailed study. The relationship between the degree of deterioration of concrete on one side and the severity of exposure conditions and the properties of concrete on the other side has been studied by the application of rank correlation analysis.

1976

A-191 Fookes, P. G. and Collis, L., "Cracking and the Middle East," Concrete (London), Vol 10, No. 2, Feb 1976, pp 14-19.

In the Middle East concretes crack for reasons similar to those which cause cracking in any other part of the world, with perhaps the exception of freezing. However, certain cracking processes are accentuated by the presence of salts in the ground and in the aggregates, and by the climatic environment. This article discusses forms of cracking and deterioration directly related to the presence of salts, and also suggests some protective measures.

A-192 "Corrosion of Reinforcement in Concrete," Materials and Structures, Research and Testing (Paris), RILEM Technical Committee, CRC, Vol 9, No. 51, May/Jun 1976, pp 187-206.

A state-of-the-art report on the corrosion of reinforcement and prestressing tendons in concrete.

Most structures are free from corrosion trouble and many have given very satisfactory long-term service. When corrosion of the reinforcement does occur it is usually associated with faulty construction, a very aggressive environment, or a change of use such as the introduction of wet conditions into a previously dry structure. Corrosion of the reinforcement can impair the strength of a structure and its effects are often unsightly. Repair is usually expensive and it is therefore desirable to avoid conditions which might lead to its occurrence.

This report collects information on the causes and processes of corrosion so that this knowledge can be used to reduce the risk of corrosion in new construction. Since the use of prestressed concrete or lightweight concrete introduces several requirements which are additional to those for reinforced concrete of normal quality, these requirements are dealt with in separate chapters.

A-193 Podvalnyi, A. M., "Phenomenological Aspect of Concrete Durability Theory," Materials and Structures, Research and Testing (Paris), Vol 1, No. 51, May/Jun 1976, pp 151-162.

It is shown that concrete destruction by freezing and thawing, in dry and hot climate, under sulfate and potassium aggression occurs because of high inner tensile stresses appearing as a result of bonding of the components with widely different deformations under the action of corrosion. The problem of concrete frost resistance is considered in detail. The model of concrete as a material of "conglomerate in conglomerate" type, divided into three structural levels, is proposed. The measurement of damage to concrete characterized by the ratio of maximum total inner stresses to local strength of structure is introduced. It is shown that the developed approach makes it possible to explain from a single viewpoint the majority of experimental facts known in the field of concrete durability.

A-194 O'Neil, E. F., "Durability and Behavior of Prestressed Concrete Beams; Laboratory Tests of Weathered Pretensioned Beams," Technical Report No. 6-570, Report 5, Jun 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report is the fifth in a series describing a study which is being conducted to develop information on the durability of prestressed (pretensioned and posttensioned) concrete beams. This report describes tests and observations on two beams that had been exposed to severe weathering for 16 years in a flexurally loaded condition at the Treat Island, Maine, exposure station. This phase of the study was conducted in the same manner as that described in Report 3 of this series, and the beams used were the same as those from Treat Island described in Report 3, with the exception of the loading condition of the beams during the years of weathering.

The laboratory tests conducted on these beams consisted of examination and tensile testing of the steel prestressing (pretensioning) strands after removal from the beams and also tests to determine depths of carbonation and chloride penetration into the test beams.

A-195 Diamond, S., "Review of Alkali-Silica Reactions and Expansion Mechanisms. 2. Reactive Aggregates," Cement and Concrete Research, Vol 6, No. 4, Jul 1976, pp 549-560.

Recent literature on the properties of aggregates that take part in alkali-silica or alkali-silicate reactions is reviewed, with special emphasis on those features which are thought to influence the mechanisms and kinetics of alkali attack.

A-196 Byers, W. G., "Field Procedure for Evaluating Potential Sulfate Damage to Concrete," Proceedings, American Concrete Institute, Journal, Vol 73, No. 8, Aug 1976, pp 443-444.

Describes a method for determining the sulfate content of water and soils involving minimum equipment and suitable for field use. The method identifies waters or soils requiring the use of Type 2 or Type 5 cement for satisfactory concrete durability.

A-197 Smith, D. W., "Bridge Failures," Proceedings, Institution of Civil Engineers (London), Part 1, Design and Construction, Vol 60, Aug 1976, pp 367-382.

The most common causes of bridge failure are indicated by classified tables of actual examples. Brief details of each failure are given, and the stage of life of the structure at which the failure occurred. Certain instances are selected for more extended description and comment.

The bridge failures are tabulated under the following headings: failures during construction; failures within two years of completion; failures more than two years after completion; and a summary of these tables. Failures of 143 bridges in all are described. Causes of failure are grouped under nine headings in the fourth table: inadequate or unsuitable temporary works or erection procedures; inadequate design in permanent material; unsuitable or defective permanent material or workmanship; wind; earthquake; flood and foundation movement; fatigue; corrosion; and overload or accident.

A-198 Hunnicutt, J. M., "Parking Deck Deterioration - The Reasons Why," Concrete Construction, Vol 21, No. 9, Sep 1976, pp 444-448.

There are two main reasons why many garages begin to have serious structural problems within eight to ten years after they are built. The first is unfamiliarity by the designer with the use and operational characteristics of this kind of building. The second is lack of adequate drainage and waterproofing.

The biggest single cause of parking deck deterioration is again the design - expansion joints that are designed improperly (usually of inadequate size) and put in the wrong places, control joints too far apart or in the wrong places with respect to the ramp system used, and as cited above inadequate (or nonexistent) drainage and waterproofing.

Few of the products marketed by a large number of manufacturers seal and waterproof as they claim. Products developed for waterproofing retaining walls and foundations do not necessarily work equally well on parking garage decks. There are several concepts being applied to waterproofing of parking garages. Four of these systems are discussed here. Waterproofing specifications calling for evidence of previous successful applications and a guarantee are described. Joint control and slab rehabilitation are also briefly examined.

A-199 Imai, M., "Investigation of Concrete Damaged By Freezing," Japan Concrete Journal (Tokyo), Vol 14, No. 11, Nov 1976, pp 16-22.

Durability, strength, and water impermeability are important qualities which a concrete structure is required to have. In the regions which have heavy weather such as Hokkaido, Japan, a concrete structure is inclined to be damaged and deteriorated by repeated freezing and thawing. Hence the selection of materials, composition, and construction requires thought.

This paper studies the influence of materials, composition, environment condition, and the age of concrete structure by means of the investigation of concrete structures damaged by freezing which were constructed in the last nine years.

A-200 Ludwig, U., "Influence of Alkali-Aggregate Reaction (Einflüsse auf die Alkali-Zuschlag-Reaktion)," Cement and Concrete Research, Vol 6, No. 6, Nov 1976, pp 765-772.

Results are described of work done on the influence on concrete damaging reaction caused by the chemical and mineralogical composition as well as by the bulk density of opaline sandstone. Furthermore, the influence of the addition of water saturated and dry sandstone on the alkali reaction is shown. Experiments have also been performed to investigate the equilibrium humidity of the alkali-aggregate reaction, the efficiency of a suitable moisture repellent, and the influence of fly ash.

A-201 Bergstrom, S. G., "Influence of Frost on the Physical and Mechanical Properties of Concrete," CBI Rapporter No. 3:76, 1976, Swedish Cement and Concrete Research Institute, Stockholm; also presented at the 2nd International Symposium on Winter Concreting, held in Moscow, 14-16 Oct, 1975.

Surveys the literature from the 1960's on the topic of the influence of frost on the physical and mechanical properties of concrete. This area has been divided into two subareas: the influence of early freezing on the properties of

the hardened concrete; and the influence of low temperatures on the properties of the hardened concrete.

A-202 Brickell, A. and Hoadley, P. J., "Thermal and Shrinkage Cracking in Reinforced Concrete Slabs," Civil Engineering Transactions, The Institution of Engineers, Sidney, Australia, Vol CE 18, No. 1, 1976, pp 24-28.

Following recent research, several mechanisms have been proposed for flexural cracking in reinforced concrete. Cracking also results from restrained volume changes in concrete, and the severity and consequences of such cracking should be considered in serviceability provisions of design codes. This paper reviews the mechanisms proposed by others for crack formation (bond slip, no slip) and suggests a "tapered bond slip" crack to reconcile their differences. A new more general formula for crack width prediction is proposed, and the amount of reinforcement required for crack control is compared with the requirements of design codes. An experimental program was conducted to test the validity of the tapered bond slip crack mechanism, and good agreement with the crack width prediction equation was achieved. It is concluded that provided a minimum ratio of reinforcement is included in a reinforced concrete member, thermal and shrinkage crack widths are a function of reinforcement ratio, age and strength of concrete, and development length of reinforcement. Cover to reinforcement has relatively little influence on such cracks. This is in contrast to recommendations for flexural crack control given in the current SAA Concrete Structures Code.

A-203 Diamond, S., "Pore Solutions and Alkali-Aggregate Attack," Proceedings, Symposium on Alkali-Aggregate Reaction-Preventative Measures (Reykjavik, Aug 1975), The Building Research Institute (Keldnaholt, Reykjavik, Iceland), 1976, pp 165-181.

Recent developments in understanding aggressive solutions developed in concrete made with high alkali cements are discussed. It appears that moderately high alkali cements produce pore solutions that become in essence concentrated alkali hydroxide solutions, of concentrations as high as 0.7 M in

both total alkalies and hydroxide ions. Calcium ion concentrations in such pore solutions drop to about 0.002 M after a few days. Results of a new extension of Debye-Huckel solution theory to calcium hydroxide in solutions of high ionic strength confirms that these pore solutions are in fact saturated with respect to calcium hydroxide. Experimental results indicating that after a few months the calcium concentration rapidly reduces to undetectable levels are discussed and a tentative explanation advanced. On the basis of this new understanding of pore solution composition it is considered that calcium should not be a significant constituent of the initial reaction product with susceptible aggregates. Recent analytical results appear to confirm that reaction product sols flowing through open cracks radiating from reacted grains pick up most of their calcium from calcium hydroxide crystals encountered by the flowing fluid and lose alkalies to the surrounding paste.

A-204 Fagerlund, G., "Studies of the Destruction Mechanism at Freezing of Porous Materials," CBI Rapporter No. 1:76, 1976, Swedish Cement and Concrete Research Institute, Stockholm; also presented at Fondation Francaise d'Etudes Nordiques, the 6th international congress on problems raised by frost action, held at Le Havre, France, 23-25 Apr 1975.

Defines and explains various aspects of freezing mechanisms of concrete. The discussion includes the critical degree of saturation, a definition of frost resistance, and of critical distance, which is the thickest completely water-saturated materials volume that may freeze without damage. Freezing of pure water and freezing of salt solution in the pore system are both discussed in detail.

A-205 Gilliott, J. E., "Practical Implications on the Mechanisms of Alkali-Aggregate Reactions," Proceedings, Symposium on Alkali-Aggregate Reaction-Preventative Measures (Reykjavik, Aug 1975), The Building Research Institute (Keldnaholt, Reykjavik, Iceland), 1976, pp 213-230.

Depletion of good quality aggregate supplies in some urban areas and the trend towards production of portland cements containing higher contents of alkali make durability failure of concrete from alkali-aggregate reaction an increased concern. A better understanding of the differenct mechanisms by which alkali causes rocks to expand, of both practical and theoretical importance, is presented. This understanding will make the identification of potentially deleterious aggregates more certain, make it easier to recognize alkali-aggregate reaction as a cause of distress in concrete, and place methods of control on a firmer foundation.

A-206 Kennerly, R. A., St. John, D. A., and Smith, L. M., "Alkali-Aggregate Reactivity in New Zealand," Proceedings, Symposium on Alkali-Aggregate Reaction-Preventative Measures (Reykjavik, Aug 1975), The Building Research Institute (Keldnaholt, Reykjavik, Iceland), 1976, pp 35-53.

The reactivity of New Zealand aggregates with cement alkalies is discussed in terms of mineral composition, behavior in laboratory tests, and performance in structures. Attention is drawn to occurrences of cracking where a high-alkali cement was inadvertently used with a glassy andesite. Petrographic evidence is cited confirming that a moderate alkali-silica reaction had occurred. Measures which have proved effective in controlling alkali-aggregate reaction in practice are given.

A-207 Lin, C. H., Walker, R. D., and Payne, W. W., "Chert-Aggregate Concrete Durability After Antifreeze Treatment," Living with Marginal Aggregates, Special Technical Publication No. 597, pp 76-84, 1976, American Society for Testing and Materials, Philadelphia, Pa.

One potential method of aggregate upgrading and analysis of its economic feasibility is illustrated. A low durability predominantly chert aggregate was used in concrete after being vacuum saturated with various liquids including plain water, solutions of water and ethylene glycol, plain ethylene glycol, and water saturated with calcium chloride. Concrete specimens were fabricated and exposed to alternate cycles of freezing and thawing in water. Concrete with aggregates saturated with 100 percent ethylene glycol showed a strong increase in

durability. The calcium chloride treatment showed no effect. An estimated cost comparison showed that aggregate production with ethylene glycol would cost about 4.5 cents per ton, as against 20 cents per ton for normal heavy-media separation treatment.

A-208 Manning, D. G., Ryell, J., "Durable Bridge Decks," Research Report No. 203, 1976, Ontario Ministry of Transportation and Communications (Research and Development Division, Ministry of Transportation and Communications, Downsview, Ontario, Canada, M3M 1J8).

Deals with bridge deck durability in Ontario and considers available techniques for the construction and restoration of bridge decks in light of existing technology. The mechanism of corrosion of reinforcing steel in concrete is outlined and the most significant factors influencing corrosion are discussed. The effect of the material properties of the steel and the concrete are presented together with a review of the environmental factors which control the onset and rate of corrosion.

Several strategies for the prevention of corrosion in bridge decks are identified and documented in turn. The relative merits of the following strategies are considered: alternative deicers, corrosion inhibitors, bar coatings, surface treatments, and impermeable overlays. Techniques for evaluating the condition of existing decks are summarized and rehabilitation procedures for existing deteriorated decks are reviewed.

It is concluded that bonded concrete overlays are the most promising method of achieving the goal of maintenance-free bridge decks. It is therefore recommended that bonded overlays be applied to new decks in a two-course construction technique and to existing decks as the basis of permanent repair procedure. The report also identifies future research and development needs and contains a comprehensive reference list.

A-209 <u>Proceedings, Symposium on Alkali-Aggregate Reaction-Preventative Measures</u> The Building Research Institute (Keldnaholt, Reykjavik, Iceland), 1976.

This international conference, presenting recent research on alkali-aggregate reactions, was held in Reykjavik, Iceland, in August 1975. The conference was cosponsored by the Icelandic Building Research Institute and the State Cement Works. Research topics included the kinds of alkali-aggregate (or alkali-silica) reactions that occur, the mechanisms by which the damage is done, and the kinds of aggregates that participate in the reactions. Case studies of the kinds of rocks and circumstances causing reactions in specific cases are presented. Papers consider the aggregates, cements, cement pastes, or combinations of these. Methods for identifying and classifying reactive aggregates are discussed. The cement production processes and the effect of plant configuration on the alkali content of the resulting cements are also discussed. The reaction and expansion processes of alkali-aggregate reactions are described. Finally, ways of integrating and applying alkali-aggregate reactions to practical concrete technology are given.

A-210 Sprung, S., "Influence on the Alkali-Aggregate Reaction in Concrete," Proceedings, Symposium on Alkali-Aggregate Reaction-Preventive Measures (Reykjavik, Aug 1975), The Building Research Institute (Keldnaholt, Reykjavik, Iceland), 1976, pp 231-244.

American, Australian, and Danish investigations on concrete deterioration as a result of alkali-aggregate reaction show among other factors that the type of the reactive aggregate, its grain size and quantity, the alkali content of the cement, and the conditions during storage and use of concrete are of special importance. In the last few years there has also been evidence of an alkali-aggregate reaction in Germany which could be attributed to the Eozän opal-containing sandstone occurring to a limited extent in North Germany. Consequently, the main objective of the investigation was to describe the influences, to evaluate their significance for the building sector, particularly in North Germany, and on the basis of gained knowledge to derive guiding directives for constructing with aggregate materials which may contain alkali-reactive constituents.

A-211 Vivian, H. E., "Alkali-Aggregate Reaction," Proceedings, Symposium on Alkali-Aggregate Reaction-Preventive Measures (Reykjavik, Aug 1975), The Building Research Institute (Keldnaholt, Reykjavik, Iceland), 1976, pp 21-34.

The various aspects of alkali-aggregate reaction in concrete are described and discussed in some detail. The highly significant material factors and the modifying influence of environmental factors are pointed out and their effects on the mechanisms of reaction and expansion are discussed. The most widely used test procedures are indicated briefly and comments on the interpretation of test results obtained by them are given. Comments are also included on the signs and symptoms used for recognizing alkali-aggregate reaction in existing structures and on ways of preventing reaction in new construction.

1977

A-212 O'Neil, E. F., "Durability and Behavior of Prestressed Concrete Beams; Posttensioned Concrete Beam Investigation with Laboratory Tests from June 1961 to September 1975," Technical Report No. 6-570, Report 4, Feb 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report is the fourth in a series describing a study which is being conducted to develop information on the durability of prestressed concrete beams. If no further testing is done to the remaining 12 beams left at Treat Island, Maine, this will be the final report of the posttensioning concrete investigation.

Twenty posttensioned concrete beams were cast between 23 September 1960 and 3 March 1961 and installed at the Treat Island exposure station in June 1961. The beams were cast around four different types of posttensioning systems, with the posttensioning reinforcement cast at four different eccentricities. Twelve different types of end anchorage protection were cast over external and flush anchorages. The end anchorage protection was attached to the beam with four different types of joint preparation.

The beams were subjected to tidal inundations (wetting and drying) two times each day and also to an average of 131 cycles of freezing and thawing per winter for a test period of 12 to 13 winters.

During the fall of 1973, five beams were returned to the U. S. Army Engineer Waterways Experiment Station for autopsy and testing. Three additional beams were returned during the fall of 1974 for the same purpose. The testing included: (a) structural testing, visual evaluation of the condition,

and dissection of the concrete beams; (b) visual evaluation of the end anchorages and the posttensioning conduit; (c) autopsy of the posttensioning system; (d) structural testing of the posttensioning strands: (e) analysis of the products of corrosion on the steel strands; and (f) analysis of the concrete and grout of the beams.

A-213 Colgate, D., "Cavitation Damage in Hydraulic Structures," Paper presented at the International Conference on Wear of Materials, St. Louis, Mo., Apr 1977, pp 433-438.

Cavitation is a hydrodynamic phenomenon including the inception, growth, and collapse of vapor cavities in a localized area where the dynamic pressure on a liquid has been reduced to the vapor pressure of the liquid. The type of cavitation considered in this writing is that which may be encountered in hydraulic structures and machines. The energy to sustain the vapor cavity is derived from flowing water, and the ambient pressure in the surrounding liquid controls the growth and collapse of the cavity. Cavitation in hydraulic structures is objectionable because the collapsing cavities produce intense noise and vibration, and flow boundaries in the cavity collapse zone are subjected to cavitation damage.

A-214 Hart, E. D., "Sluice Cavitation and Vibration Problems, Libby Dam, Montana," Paper presented at the International Conference on Wear of Materials, St. Louis, Mo., Apr 1977.

Libby Dam, a combined flood control, power, and recreation project, is located on the Kootenai River 17 miles upstream from the town of Libby, Montana. Flow past the dam is accomplished by sluices, spillway, and turbines. The three, 10-ft by 17-ft sluices (designated left, center, and right looking downstream) were designed to operate with up to 265 ft of head and at a total discharge of 61,000 cfs. Reservoir regulation began on 21 March 1972 with all outflow regulated by the sluices. Extreme cavitation damage was discovered in the center sluice on 20 September 1973 and again in the right sluice on 24 July 1974. Unprecedented noise and vibrations were experienced when a sluice gate was opened to the 16-17-ft range. The cavitation damage was repaired, a periodic sluice inspection program was initiated, and sluice operation

restrictions are now in effect. During the repair of the center sluice, nine pressure transducer mounting boxes were placed in the sluice floor. Prototype testing was accomplished in July 1974 which included recordings of pressures on the sluice invert at the transducer locations, and vibrational conditions on the sluice gate and dam structure.

Undated

A-215 Beaton, J. L, "Factors Affecting Abrasion Resistance of Concrete Surfaces," PB 173042, Clearinghouse for Federal Scientific and Technical Information.

Reports results of a laboratory research program on abrasion resistance of concrete. Variables studied were slump, finishing, curing, surface treatments, and admixtures. Also slump and finishing techniques had an appreciable effect on abrasion resistance, the broadest range of abrasion losses encountered were those related to curing procedures.

Benefits, both preventive and remedial, may be realized by linseed oil treatment. This procedure is suggested for areas where deicing agents are used.

Apparatus and test method for determining surface abrasion resistance by impact in the presence of water is described.

A-216 Dolar-Mantuani, L., "Late-Expansion Alkali-Reactive Carbonate Rocks," Highway Research Record No. 353, pp 1-14.

Some alkali-reactive carbonate rocks of the Ordovician Gull River formation in Ontario are characterized by a shrinkage period preceding expansion when tested in 1N sodium hydroxide. These late-expansion rocks have a shrinkage period of at least 10 weeks, maximum shrinkage of at least 0.03 percent, and later minimum expansion of 0.20 percent. Petrographic examinations show the rocks to be sandy or silty argillaceous calcitic dolomites. Typical samples have 3 to 5 percent absorption, bulk specific gravity below 2.60, more than 20 percent acid-insoluable residues, and 75 to 87 percent dolomite in the carbonates.

A-217 "Factors Affecting the Durability of Concrete Bridge Decks," Interim Report PO 2, Research Study D-3-29, California Division of Highways.

Studies of four separate bridge construction jobs completed in bridge deck cracking research. Significant evaluations of construction practices, air-entrainment, and attention to curing and weather conditions are revealed. Poor initial curing is defined as major contributing cause to excessive deck cracking.

A-218 Halstead, P. E., "An Investigation of the Erosive Effect on Concrete of Soft Water of Low pH Value," Magazine of Concrete Research, Vol 6, No. 17, pp 93-98.

An investigation is described in which the effect of soft moorland water on concrete has been studied by tests on 4-in. concrete cubes. Cubes were immersed in moorland water or tap water for periods of up to four years and were then weighed and crushed to determine their compressive strength. After immersion in soft water, all types of concrete lost strength and weight to an extent which increased as the immersion was prolonged. Cubes made of Portland cement concrete of very high strength or high alumina cement concrete lost about one-third of their strength after four years immersion. Cubes of concrete of all other types, irrespective of strength or kind of cement used, lost about half their strength after four years immersion. Concrete containing entrained air behaved similarly, but concrete painted with bitumen maintained its strength while the coating was intact.

SECTION B

EVALUATING THE CONDITION OF

EXISTING STRUCTURES

1937

B-1 Williams, J. F., "Method For Estimation of Compressive Strength of Concrete in the Field," Structural Engineer, Vol 14, No. 7, Jul 1937, pp 321-326.

Description of pistol like portable instrument for testing compressive strength by measurement of its resistance to impact; results of 200 tests.

B-2 Spencer, R. W., "Measurement of Moisture Content of Concrete," Proceedings, American Concrete Institute, Journal, Vol 9, No. 1, Sep-Oct 1937, pp 45-61.

Development of electric resistance methods for rapid determination of moisture content of concrete structures at any time in their history; resistance of concrete at early ages; effect of type of cement on conductance of concrete; electrode calibration chart; moisture tests on slabs in Colorado river desert, in tunnel lining, and in Morris dam mass concrete.

1938

B-3 Skramtajew, B. G., "Determining Concrete Strength for Control of Concrete in Structures," Proceedings, American Concrete Institute, Vol 34, Jan-Feb 1938, pp 285-304.

Good concrete control methods require testing concrete in the finished structure as well as the usual specimens made at the time of placing. Fourteen methods of testing concrete in the finished structure are described, half of them requiring preliminary measures when placing the concrete. These tests are much more cumbersome than the other half which may be performed any time at any point. It is suggested that both types be used together.

1939

B-4 Hornibrook, F. B., "Application of Sonic Method to Freezing and Thawing Studies of Concrete," Bulletin No. 101, pp 5-8, Dec 1939, American Society for Testing and Materials, Philadelphia, Pa.

Apparatus for determining fundamental flexural frequency of specimen vibrating as free-free bar developed and used at National Bureau of Standards, described; data obtained in testing concretes subjected to cycles of freezing and thawing; effect of change in temperature and moisture content on natural frequency of concrete specimens.

1940

B-5 Thomson, W. T., "Measuring Changes in Physical Properties of Concrete by Dynamic Method," Preprint No. 72, pp 24-28, Jun 1940, American Society for Testing and Materials, Philadelphia, Pa.

Tests of modulus of elasticity and period of vibrations of concrete with different water-cement ratios; testing apparatus consists of heat frequency oscillator with frequency range of 0 to 3000 cycles, magnetic pick-up connected to audio-frequency amplifier and output meter registering amplitude of vibration.

1941

B-6 Obert, L, and Duvall, W. I., "Discussion of Dynamic Methods of Testing Concrete with Suggestions for Standardization," Proceedings, American Society for Testing and Materials, Philadelphia, Pa., Vol 41, 1941, pp 1053-1070.

To assist in standardizing dynamic methods of testing concrete, underlying theory, apparatus, effects of moisture, and size of specimen have been studied and findings are presented; results of previous investigations; new experimental data from which conclusions are drawn as to best methods of standardization.

B-7 Pigman, G. L., "Vacuum Method of Measuring Air Content of Fresh Concrete," Proceedings, American Concrete Institute, Journal, Vol 13, No. 2, Nov 1941, pp 121-129.

Method has been developed in which air is removed at reduced absolute pressure of approximately 17 mm of mercury; determination of air content is made entirely by volume measurements and does not require any information of specific gravity of components of concrete.

1943

B-8 Walker, S., "Computation of 'Dynamic Modulus'," Bulletin No. 121, pp 23-24, Mar 1943, American Society for Testing and Materials, Philadelphia, Pa.,

Modulus of elasticity as determined from measurements of fundamental frequencies of test specimens is useful in investigations of concrete; formula reported by OBERT and DUVALL, based on solutions by TIMOSHENKO and GOENS for specimens vibrating in flexure in free-free mode, is given which affords accepted basis for computations.

1944

B-9 Young, R. B., "Device for Determining Depth of Surface Cracks in Concrete," Proceedings, American Concrete Institute, Journal, Vol 15, No. 5, Apr 1944, pp 401-406.

Device is described as consisting essentially of pressure tank, air pump, and pressure gage, together with pipes, valves, and fittings by which dye solution is forced into crack to be explored; then by drilling, crack is followed inward until it is bottomed; depth of crack is established by pressure test; some results obtained using device are reported.

1945

B-10 Long, B. G., Kurtz, H. J., Sandenaw, T. A., "Instrument and Technique for Field Determination of Modulus of Elasticity, and Flexural Strength of Concrete," Proceedings, American Concrete Institute, Journal, Vol 16, No. 3, Jan 1945, pp 217-231.

Description of instrument for determination of dynamic modulus of elasticity of concrete, in situ; advantages of instrument; method for determining thickness of concrete pavements.

1948

B-11 Graham, B. L., "Hydro's Ultrasonic Eye," Hydro News, Vol 35, No. 6, Jun 1948, pp 10-11 and 30.

Description of ultrasonic methods of detecting cracks in concrete dams; apparatus operates on principle that ultrasonic waves are reflected backwards or dispersed on encountering crack or void in solid body such as concrete; illustrations show "crack detector" in operation.

1949

B-12 Jones, R., "Measurement of the Thickness of Concrete Pavement by Dynamic Methods: A Survey of the Difficulties," Magazine of Concrete Research, Vol 1, No. 1, Jan 1949, pp 31-34.

This note reviews the practical difficulties and errors occurring in the methods employed in determining the thickness of concrete pavements by nondestructive methods based on the propagation of sound waves in the pavement.

Most of the methods give errors in the determination of the thickness of imperfectly compacted slabs when a variation of sound velocity occurs with depth in the slab, but calculations are given which show that the method based on the reflection of an ultrasonic pulse by the bottom of the slab could be made to yield accurate results should the present experimental difficulties be overcome.

B-13 Jones, R., "Non-Destructive Method of Testing Concrete During Hardening," Concrete and Construction Engineering, Vol 44, No. 4, Apr 1949, pp 127-129.

Application of ultrasonic method for nondestructive testing of concrete; velocity of ultrasonic pulse in concrete is used as criterion of its quality to study properties of concrete at very early ages; method is used on actual structural member and not on test samples.

B-14 Leslie, J. R. and Cheesman, W. J., "Ultrasonic Method of Studying Deterioration and Cracking in Concrete Structures," Proceedings, American Concrete Institute, Journal, Vol 21, No. 1, Sep 1949, pp 17-36.

"Soniscope" used to detect internal cracks in concrete develops pulses of ultrasonic sound in material and measures velocity of their transmission through it: method can be applied to any size or shape of body under test; examples illustrated.

B-15 Jones, R., "The Non-Destructive Testing of Concrete," Magazine of Concrete Research, 1949, pp 67-78.

A method is described which has been used to determine the velocity of longitudinal waves in concrete specimens by measuring the time taken for an ultrasonic pulse to travel through a known length of concrete. Results are given which illustrate the use of the method for studying the variations occurring among laboratory specimens.

The value of the longitudinal wave velocity as an index quality is discussed, with reference to tests made on a variety of specimens subsequently subjected to compressive and flexural strength tests and density analysis. Deterioration of concrete quality due to freezing and thawing can be detected before superficial damage occurs.

The Poisson's ratio of several types of concrete has been measured and values from 0.16 to 0.31 obtained depending mainly upon the type of aggregate.

<u>1950</u>

B-16 Jones, R., "Testing Quality of Concrete in Thick Wall," <u>Concrete and Constructional Engineering</u>, Vol 45, No. 11, Nov 1950, pp 391-394.

Report on nondestructive tests carried out by British Road Research Laboratory on reservoir walls 3 ft 6 in. and 4 ft 3 in. thick; tests using two piezoelectric crystal transducers described; measurement of mechanical vibrations produced by electrically shock exciting one of transducers; relation between longitudinal wave velocity and compressive strength.

<u>1951</u>

B-17 Jones, R., "Non-Destructive Testing of Concrete," <u>Reinforced Concrete Review</u>, Vol 2, No. 5, Jan 1951, pp 315-321.

Measurement of longitudinal wave velocity; relation between longitudinal wave velocity and compressive cube strength at 28 days; increase of longitudinal wave velocity in setting concretes and mortars; laboratory and field applications of method; effect of freezing and thawing on different concrete mixes; Poisson's ratio for different concretes at ages greater than 28 days.

B-18 Whitehurst, E. A., "Soniscope Tests Concrete Structures," <u>Proceedings, American Concrete Institute, Journal</u>, Vol 22, No. 6, Feb 1951, pp 433-444.

Soniscope, an instrument which measures group velocities through as much as 50 ft of concrete, was used for field testing of bridges, navigation locks, dams and highway pavements in 12 states; study of changes in condition of concrete; development of group velocities indicated condition of structure.

B-19 Schmidt, E., "Der Beton-Pruefhammer," <u>Concrete</u>, Vol 59, No. 8, Aug 1951, pp 34-35.

Concrete testing hammer, apparatus for determining quality of concrete in structure, described.

B-20 Goodell, E. C., "Improved Sonic Apparatus for Determining the Dynamic Modulus of Concrete Specimens," Proceedings, American Concrete Institute, Journal, Vol 47, 1951, pp 53-60.

After a brief introduction to sonic testing and a description of commercial equipment, the apparatus built for the Michigan State Highway Department is discussed. Reliable results can be obtained by an unskilled worker with this compact equipment which has twice the frequency band spread of the usual oscillator. A wiring diagram of the sonic apparatus is included.

1952

B-21 Andersen, J. and Nerenst, P., "Wave Velocity in Concrete," Proceedings, American Concrete Institute, Journal, Vol 23, No. 8, Apr 1952, pp 613-635.

Danish timing device and its application to determination of wave velocity in concrete specimens; hypothesis for relation between wave velocity and age; calculating wave velocity; estimate of concrete homogeneity.

B-22 Harvey, H. A., "New Surface-Applied Instrument Tests Condition and Quality of Concrete," Roads and Engineering Construction, Vol 90, No. 5, May 1952, pp 77-79 and 130.

Method of testing concrete structures and determining presence of internal voids and depth of cracks; equipment, known as Soniscope, has other fields of usefulness including determination of degree of compaction of soil. Soniscope consists of transmitter, receiver and indicator; relation between pulse velocity, dynamic modulus and quality.

1953

B-23 Leslie, J. R., "Supersonics Test Concrete Structures," Electrical World, Vol 139, No. 18, May 1953, p 79.

Developed by Hydro-Electric Power Commission of Ontario, Soniscope uses supersonic sound waves to nondestructively investigate deterioration in dams and other large concrete structures; pulses of supersonic waves detect and outline flaws and follow progress of deterioration; instrument is made up of transmitter, receiver, and electronic control unit.

1954

B-24 Roshore, E. C., "Ultrasonic Investigation of Cracking in Kansas City Floodwall (Armourdale Unit)," Miscellaneous Paper No. 6-72, May 1954, U. S. Army Corps of Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

During the Kansas River flood of 13 July 1951, the Armourdale Unit of the Kansas City, Kansas, floodwall was damaged by a reverse water load which caused cracking. Manual soundings were taken to ascertain the extent of the cracking and a contract was let for repair of the wall stems. The Kansas City District requested verifcation of the manual soundings by means of a soniscope survey of the monoliths in question.

The soniscope is an instrument for measuring the transmission time of a pulsed wave through concrete. If cracking or deterioration is present, it is detected by the pulse velocity through the affected area being lower than the velocity determined for normal concrete.

The survey at Kansas City involved determination of the extent of vertical cracking in 17 monoliths.

B-25 Stutterheim, N., Lochner, J. P. A., and Burger, J. F., "A Method for Determing the Dynamic Young's Modulus of Concrete Specimens Developed for Corrosion Studies," Magazine of Concrete Research, Vol 6, No. 16, Jun 1954, pp 39-46.

The effect of aggressive environments on concrete can conveniently be studied by observing the resultant changes in the dynamic modulus of elasticity of test specimens. An apparatus for rapid and accurate measurement of the fundamental transverse and longitudinal frequencies of a 1-by 1-by 11 in. concrete specimen is described. Typical experimental results are presented.

B-26 Green, G. W., "Test Hammer Provides New Method of Evaluating Hardened Concrete," Proceedings, American Concrete Institute, Journal, Vol 26, No. 3, Nov 1954, pp 249-256.

E. SCHMIDT concrete test hammer provides convenient nondestructive method of determining strength of concrete mass that has smooth, flat surface; results of tests made with instrument are compared with results of compression and flexure tests.

B-27 Jones, R. and Wettern, J. H., "Testing Strength of Concrete by Ultrasonic-Pulse Method," Concrete and Construction Engineering, Vol 49, No. 11, Nov 1954, pp 343-347.

Use of method to assess strength of precast units to form sections of primary and secondary beams which were to be assembled and prestressed on site for form beams in new school building.

B-28 Pogany, A., "Non-Destructive Method of Testing Strength of Concrete," Civil Engineering (London), Vol 49, No. 581, Nov 1954, pp 1193-1194.

Determination of strength can be reduced to determination of porosity; nondestructive method of porosity determination.

<u>1955</u>

B-29 Philleo, R. E., "Comparison of Results of Three Methods for Determining Young's Modulus of Elasticity of Concrete," <u>Proceedings, American Concrete Institute</u>, Vol 51, Jan 1955, pp 461-472.

The elastic response of concrete to static, resonance, and pulse velocity tests is discussed. Because of the wide variations in static testing techniques and the heterogeneity of concrete, the results of Young's modulus calculated from the three methods do not necessarily agree. The pulse velocity method has advantages over the other two in that testing is not confined to regularly-shaped laboratory specimens, and results are free from inelastic effects. The method, however, has severe limitations: it is so affected by the heterogeneity of concrete that calculations of Young's modulus are discouraged, and it is not sensitive to small changes in the paste component of concrete.

B-30 Simmons, J. C., "Poisson's Ratio of Concrete: Comparison of Dynamic and Static Measurements," <u>Magazine of Concrete Research</u>, Vol 7, No. 20, Jul 1955, pp 61-68.

Tests carried out to determine values of Poisson's ratio: three values determined, static value and two values derived from dynamic tests; values are related to each other and to other properties of concrete; from results of dynamic tests, equation is derived by which dynamic elastic modulus may be determined from measurements of ultrasonic pulse velocity.

B-31 Kaplan, M. F., "Recent Developments in Non-Destructive Methods of Testing Concrete with Particular Reference to the Ultrasonic Pulse Technique," <u>Transactions, South African Institution of Civil Engineers</u>, Vol 5, No. 8, Aug 1955, p 243.

In recent years considerable developments have taken place in non-destructive methods of testing concrete. This paper reviews these developments and makes particular reference to the ultrasonic pulse method which is considered to be the best method yet developed for testing the quality of concrete in structures.

B-32 Werden, A. C., Jr., "Testing Concrete Dams Nondestructively," Electric Light and Power, Vol 33, No. 9, Aug 1955, pp 70-71.

Strength and rate of deterioration of concrete in dams, determined accurately and nondestructively by supersonic testing method used by Southern California Edison; soniscope transmits pulses of supersonic energy into concrete and electronically measures travel time from transmitter on one face to receiver on distant face of concrete.

B-33 Jones, R. and Gatfield, E. N., "Testing Concrete by Ultrasonic Pulse Techniques," Technical Paper No. 34, 1955, Great Britain Department of Science and Industrial Research - Road Research Laboratory.

Apparatus for making high precision measurements of velocity of ultrasonic pulse in concrete; method can be applied to concrete in situ and can be used to detect any weakness due to deterioration or poor compaction; examples of use of method with detailed account of determination of strength of concrete in walls of reservoir.

1956

B-34 Chaturvedi, D. C., Gupta, G. C., and Srivastava, H. D., "Investigation of Properties of Concrete by Non-Destructive Method (Sonic Apparatus)," Journal, Institution of Engineers (India), Part 1, Vol 36, No. 8, Apr 1956, pp 1645-1655.

Method used for determining value of elasticity of specimen; investigation on quality of concrete shows that value of elasticity determined by this method can easily be correlated to any of its important properties, like ultimate crushing strength of flexural strength.

B-35 Laverty, B. R. and Palmrose, E. W., "Soniscope Testing of Dams," Electronic West, Vol 117, No. 3, Sep 1956, pp 116-118.

California Edison Co's nondestructive method for testing performance of concrete dams at Big Creek-San Joaquin River hydroelectric development; method used is based on determining velocity of ultrasonic pulse propagation through concrete with electronic instrument called soniscope; other applications include tests of concrete structures, steel shafting and compacted soil.

B-36 Armstrong, C. C., Ulp, R. B., and Larson, K. C., "Sonic Method Proves Valuable for Testing Concrete Specimens," Civil Engineering (N.Y.), Vol 26, No. 11, Nov 1956, pp 58-61.

By using sonic method of testing, moment of inertia can be solved for directly, no matter what shape or geometric configuration sample may take; examination of concrete blocks with from one to three holes has been completed and theory has proved reliable; special application would prove helpful in study of stresses in honeycomb sections.

1957

B-37 Kesler, C. E. and Chang, T. S., "Review of Sonic Methods for Determination of Mechanical Properties of Solid Materials," Bulletin 225, pp 40-46, Oct 1957, American Society for Testing and Materials, Philadelphia, Pa.

Discussion of various resonant frequency and wave velocity methods; references to testing of concrete, particularly use of soniscope and interval timer for this purpose.

B-38 Whitehurst, E. A., "Dynamic Testing of Concrete Evaluated," Civil Engineering, (N. Y.), Vol 29, No. 12, Dec 1957, pp 57-59.

New applications in nondestructive concrete testing described; velocity of pulse propagation; evaluating strength of concrete; determination of sources of error.

<u>1958</u>

B-39 Forrester, J. A., "Application of Gamma Radiography to Concrete," <u>Engineer</u>, Vol 205, No. 5327, Feb 28, 1958, pp 314-315.

Use of gamma radiography as a nondestructive and relatively inexpensive method of testing certain properties of cement products in concrete and cast stone and in concrete research is described.

B-40 Kaplan, M. F., "Compressive Strength and Ultrasonic Pulse Velocity Relationships for Concrete in Columns," <u>Proceedings, American Concrete Institute</u>, Vol 54, Feb 1958, pp 675-688.

Reports an investigation to determine to what extent compressive strength and pulse velocity tests indicate the variability and compressive strength of concrete as it exists in a series of columns. Concrete cubes site-cured under the same atmospheric conditions as the concrete columns had a compressive strength averaging 10 percent lower than the strength of the concrete in the columns. Concrete cubes continuously cured under water averaged 23 percent higher strength than the concrete in the columns.

When the pulse velocity in the columns was measured, the corresponding compressive strength as obtained from the pulse velocity-strength relationship for the site cubes averaged 18 percent lower than the actual strength of the concrete in the columns. The compressive strength obtained from the relationship for cubes continuously cured under water averaged 29 percent lower than the actual strength. Pulse velocity values for the concrete in the columns gave a better indication of the variation in strength quality of the concrete than did compressive strength results on concrete cubes.

B-41 Cawkell, A. E., "Investigation of Quality of Thick Concrete by Ultrasonic Pulse Propagation," <u>Magazine of Concrete Research</u>, Vol 10, No. 28, Mar 1958, pp 23-26.

Velocity of ultrasonic pulses through concrete is measured by oscillograph timing technique; to increase range about 8 ft through good quality concrete with standard instrument, higher power, and low frequency, sharply directional

magnetostriction transducers were used in tests; 20 ft is maximum path length possible with this method.

B-42 Kolek, J., "Appreciation of Schmidt Rebound Hammer," Magazine of Concrete Research, Vol 10, No. 28, Mar 1958, pp 27-36.

Schmidt rebound hammer is described and theoretical aspects underlying functioning of hammer are discussed and supported by experimental results; correlations with rate of wear of concrete and compressive strength on basis of 500 cube results are derived; hammer is recommended for use on building site and in precast works.

B-43 "Field Soniscope Tests of Concrete; 1953-1957 Tests," Technical Memorandum No. 6-383, Report 2, Mar 1958, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

In 1957 pulse velocities were determined at 160 stations in four dams, one lock, and specimens at field exposure station; changes in concrete measurable by pulse velocity were minor at all but four stations, and permit no conclusions concerning general trend of concrete to increase or decrease significantly in quality; at four stations in lock, pulse velocity increased significantly.

B-44 Grieb, W. E., "Use of Swiss Hammer for Estimating Compressive Strength of Hardened Concrete," Public Roads, Vol 30, No. 2, Jun 1958, pp 45-52.

Portable instrument is being used in field to gage increases in concrete strength with age and in locating low-strength areas; useful in surveys of old structures; surface moisture, and type of coarse aggregate affect strength values obtained by device.

B-45 Willetts, C. H., "Investigation of the Schmidt Concrete Test Hammer," Miscellaneous Paper No. 6-267, Jun 1958, U. S. Army Engineer

Waterways Experiment Station, CE, Vicksburg, Miss.

This investigation consisted of a series of tests designed to evaluate the readings (indicating quality and strength) obtained by use of the Schmidt hammer on hardened concrete surfaces by correlating them with results obtained by conventional test methods under the same controlled test conditions. Tests were made on four 5- by 4- by 1-ft concrete panels each made with a different concrete mixture, from which were cut beams, prisms, and cores. Standard 6- by 12-in. concrete cylinders were also made from the same four concrete mixtures. The concrete for three panels contained limestone coarse and fine aggregates with cement factors of 3.5, 5.0, and 6.5 bags per cu yd. The fourth panel was made of concrete containing traprock coarse aggregate, natural silica-sand fine aggregate, and having a cement factor of 5.0 bags per cu yd. All concrete was designed to have a 2-1/2 ± 1/2-in. slump and an air content of 5 ± 1-1/2 percent. Maximum size aggregate for all panels used was 1-1/2-in.

Tests were made with the Schmidt hammer on the wet and dry faces of the panels in a horizontal and then in a vertical position. All hammer tests were conducted in accordance with instructions issued by the manufacturer. Each square of each panel was subjected to 30 blows from the hammer (15 for each position of the panel face), which were carefully randomized over the 1-sq-ft area. After the hammer tests were completed, cores, beams, and prisms were extracted from the panels and tested for compressive (cores and prisms) and flexural (beams) strength.

The information derived from this investigation indicated that the Schmidt hammer can be used to estimate the strength of concrete provided it has been calibrated under the conditions for which the hammer is to be used. The curves or data developed by these tests should be used instead of graphs furnished by the manufacturer.

<u>1959</u>

B-46 Chatterjee, P. N. and Sen, B., "Use of Resonant Frequency Method as Standard for Non-Destructive Testing of Concrete," <u>Journal, Institute of Engineers</u> (India), Part 1, Vol 39, No. 10, Jun 1959, pp 985-998.

Comparison between use of resonant frequency of longitudinal vibrations recommended in British Standards, and resonant frequency of flexural vibrations recommended by American Society for Testing and Materials; factors of excitation, detection, and role of errors in linear dimensions were included in study; study points to use of flexural method for finding modulus of elasticity of concrete.

B-47 Benjamine, I. A. and Ratliff, G. D., "In-Place Strength Test for Low-Density Concrete," Bulletin No. 241, pp 23-25, Oct 1959, American Society for Testing and Materials, Philadelphia, Pa.

Nondestructive test for winter concreting studies, with which strength measurements may be taken repeatedly on specimens subjected to cycles of freezing and thawing; ASTM Method C 403-57 T, which measures rate of hardening of mortar sieved out of structural grade concrete, and is conducted by penetrating mortar with Proctor resistance needle, has been modified to measure compressive strength for low-density concrete (less than 40 lb/cu ft) over-dry density.

B-48 Meyer, R. C., "Eight Years of Pulse Velocity Tests on Concrete Pavements in Kansas," Bulletin No. 206, pp 31-36, 1959, Highway Research Board.

For the past eight years the Kansas Highway Commission has been investigating the changes in pulse velocity which occur with changes in concrete quality. A soniscope, as developed by the hydro electric power commission of Ontario, Canada, and the Portland Cement Association, has been used for making these tests. Pulse velocity tests have been made regularly on eight experimental pavements which have been constructed in Kansas. Each of these test roads are made up of a number of test sections which contain concrete of varying composition. One such test road near McPherson, Kansas, is made up of 60 test sections which contain five different brands of cement along with several pozzolanic additives. Test sections in the other experimental pavements contain concrete which in some cases is air-entrained. Other variables included in these test sections are coarse and fine ground cement, different types of aggregate, and different methods of curing. The regular tests on these several test

pavements have been made in an effort to establish a non-destructive method for studying changes in concrete quality which may not be apparent upon visual inspection. Along with the regular velocity tests made on concrete pavements, pulse velocity determinations were also made periodically on test beams containing concrete comparable to that found in the several pavement test sections. These test specimens were then loaded in flexure to failure so that the modulus of rupture could be calculated. These velocity tests were then compared with the flexural strengths to see if changes in velocity could be associated with changes in modulus of rupture. After studying the results of the large number of tests, several observations can be made. For the tests made on Kansas Highway pavements, visual evidence of deterioration is obvious before this condition is reflected in a significant change in pulse velocity. Seasonal changes in pulse velocity tend to obscure velocity trends which otherwise might be significant. Although a small change in pulse velocity is often associated with a large change in flexural strength, no good relationship between the two is apparent at this time.

B-49 "Effects of Concrete Characteristics on Pulse Velocity," Bulletin No. 206, 1959, National Research Council, Highway Research Board.

This bulletin consists of eleven papers presented at the annual meeting, Jan 6-10, 1958 in Washington, DC on the subject of use of the pulse velocity meter in appraising concrete quality and strength. Subjects covered include: Evaluation of Pulse Velocity Tests, Applications of Pulse Velocity Tests, Effect of Concrete Properties on Pulse Velocities, Apprasing Concrete Quality by Pulse Velocity Tests, and Use of the Soniscope by the Corps of Engineers.

<u>1961</u>

B-50 Shilstone, C. M. and Shilstone, J. M., "Ultrasonic Inspection of Hardened Concrete," <u>Non-Destructive Testing</u>, Vol 19, No. 1, Jan-Feb 1961, pp 39-44.

Review of testing of hardened concrete by sonic and ultrasonic methods; principal factors which affect wave velocity and strength of concrete are age, water cement ratio and aggregate

cement ratio, type of aggregate, moisture content, air entrainment, and type of cement; results indicate that ultrasonic inspection is not ready for general acceptance as basis for changing design safety factors.

1962

B-51 "A Method for Estimating the Life of Rigid Airfield Pavements," Report No. 4-23, Mar 1962, U. S. Army Corps of Engineers, Ohio River Division Laboratories.

The purpose of this report is to present a method for estimating the life of rigid airfield pavements subjected to aircraft traffic. The method presented is applicable for any type of aircraft traffic on all types of rigid pavement including overlays. An example of the use of the method is presented, and three classical examples considering paricular problems in estimating pavement life are included. It is not intended that this method of estimating pavement life be used as a basis for programming funds for new construction or reconstruction of pavements; this will only be considered when the existing physical condition of the pavement precludes initiation or continuation of the mission. This method will be found extremely useful in evaluating future operational requirements, anticipating future maintenance operations and making the most efficient use of existing pavement systems.

1963

B-52 Preiss, S. K., "Theory and Improved Techniques in the Use of Gamma Radiation for Determination of the Density of Concrete or Soils," Jun 1963, Nuclear Power Group, Department of Mechanical Engineering, Imperial College, London.

Density gages using gamma radiation have been available for over a decade. The design of these instruments has been largely empirical. This report shows how, by consideration of the nuclear processes involved, apparatus of considerably improved properties may be made.

B-53 Shankar, N. K., "Non-Destructive Testing of Concrete by Ultrasonic Methods," Indian Concrete Journal (Bombay), Vol 37, No. 7, Jul 1963, pp 262-263.

Nature of relationship between velocity of ultrasonic waves in concrete and compressive strength of concrete is explored and formula is given which determines relationship for all types of concrete; instrument designed for this type of testing and especially suited for use on construction sites is described.

B-54 Thorton, H. T., "Evaluation of Concrete by Ultrasonic Testing, F. E. Warren Auxiliary Sites, Squadron III," Miscellaneous Paper No. 6-585, Jul 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Preliminary investigations of the concrete construction in various areas of the F. E. Warren Auxiliary Sites, Squadron III, established the fact that some of the structures contained low-strength concrete. On 15 August 1960, a meeting was convened at Air Force Ballistic Missile Division to discuss the problem, identify the scope, and determine the course to be taken for the design of corrective action.

To facilitate further investigation, the Waterways Experiment Station was requested to furnish one of its soniscopes to make velocity tests on concrete at the various sites. On 19, 20, and 21 August 1960, velocity tests were made on the structures where low strength was suspected. During this same time, velocity tests were also made on 6- by 12-in. cast cylinders and on cores taken from the questionable areas. After velocity measurements were obtained on these cylinders and cores, they were subjected to compressive strength tests.

The information on pulse velocity and compressive strength obtained from the test cylinders and cores was used to establish correlation between pulse velocity and compressive strength of the concrete being investigated; this correlation and the pulse velocities obtained from the concrete in question were used to assign compressive strength values to the in-place concrete.

It was concluded that (a) a number of the areas tested had concrete of less than adequate quality, (b) some of the

suspected areas contained very uniform concrete of acceptable quality, and (c) ultrasonic testing provides a rapid, economical, and satisfactory means of surveying the quality of the concrete in structures of this and similar types.

B-55 Muenow, R., "A Sonic Method to Determine Pavement Thickness," Journal, Portland Cement Association Research and Development Laboratories, Vol 5, No. 3, Sep 1963, pp 8-21.

Presents the theoretical and practical aspects of a technique for determining the thickness of concrete slabs by nondestructive means. The technique employs the fundamental wave relationship in that a measure of the longitudinal resonant-frequency wave length, which is equal to twice the thickness, can be determined from values of pulse velocity and resonant frequency.

The data indicate that the difference between the nondestructive determination and the thickness as measured on one core is approximately 5 percent for any one point on the slab, and between 2 and 3 percent if a number of such comparisons are made along the slab. Surface cracks, other defects, and construction features may, however, increase the differences unless these influences are duly recognized and taken into consideration in interpreting the data.

The technique, besides being nondestructive, possesses the advantage of speed and ease in making tests, thereby increasing the number of tests that can be made during a given time.

B-56 Victor, D. J., "Evaluation of Hardened Field Concrete with Rebound Hammer," Indian Concrete Journal (Bombay), Vol 37, No. 11, Nov 1963, pp 407-411.

Describes an investigation regarding the usefulness of the rebound hammer for evaluating field concrete. It is found that, while a close fitting calibration curve is apparently possible when average values of a large number of results are plotted, scatter of results is too wide to facilitate any reliable inference from any individual test result. The factors affecting the rebound number-compressive strength relation are discussed.

B-57 "Non-Destructive Testing of Concrete," Bibliography No. 33, 1963, National Research Council, Highway Research Board.

Included in this bibliography (not annotated) are references to pulse velocity and sonic test methods used for measuring dynamic modulus of elasticity and for estimating strength and other properties of concrete. Some historical data and information regarding instrumentation and test procedures are also included. The 470 references cover 1889 through 1962.

The appendix contains related references on locating reinforcing steel in concrete by x-ray and gamma radiographic methods and by mine detectors, and magnetic instruments.

1964

B-58 Boundy, C. A. P. and Hondros, G., "Rapid Field Assessment of Strength of Concrete by Accelerated Curing and Schmidt Rebound Hammer," Proceedings, American Concrete Institute, Journal, Vol 61, No. 1, Jan 1964, pp 77-84.

Results of tests made on 6-in. cubes from 17 different batches of concrete suggest that rebound hammer may be used, in conjunction with some method of accelerated curing, to provide rapid and convenient field method for estimating strength and quality of concrete; some cubes were cured in water and tested in standard compression machine and remaining cubes were steam-cured and tested with rebound hammer prior to being loaded to failure in compression testing machine.

B-59 Bradfield, G. and Woodroffe, E. P. H., "Determining the Thickness of Concrete Pavements by Mechanical Waves: Diverging-Beam Method," Magazine of Concrete Research, Vol 16, No. 46, Mar 1964, pp 45-48.

By using large composite blocks of piezoelectric material, e.g., barium titanite, as separate transmitting and receiving transducers, it has been found possible to employ an echo technique for determining the thickness of concrete pavements

from about 4-18 in. without a knowledge of the velocity of the mechanical waves in the concrete being assumed. The separation of the transducers sited on the top surface was varied and as a series of travel times was measured. From these it was possible to deduce the thickness to an accuracy of about ±10 percent and, during the same analysis, to derive the velocity of the longitudinal waves in the concrete to an accuracy slightly better than ±10 percent. The presence of the subsoil support below the concrete slab caused no adverse effect.

B-60 Sims, F. W., Rhodes, J. A., and Clough, R. W., "Cracking in Norfolk Dam," Proceedings, American Concrete Institute, Journal, Vol 61, No. 3, Mar 1964, pp 265-283.

The development and detection of major transverse cracks in a mass concrete gravity dam is traced from the construction period through several years of project operation. Methods for determining the extent and size of a principal crack in one block are described.

The results of structural behavior instrumentation observations showed the crack widths have not changed substantially, that the structure exhibits an elastic response to live loads and temperature variations, and that there has been no apparent change in the stability of the structure during the past 10 years.

Application of the finite element method in the theoretical stress and displacement analysis of a cracked and uncracked gravity dam section is described. Results show stress concentrations of the order of 500 psi for the most unfavorable conditions of loading and specific crack height, and that only a moderate increase in maximum stress, to about 600 psi, will exist even when no limits are imposed on crack height.

Norfolk Dam is considered to be safe, with a single transverse crack existing in most spillway monoliths, under normal loading conditions which may be expected. Provisions are being made to limit adverse hydrostatic pressures beneath and within the structure.

<u>1965</u>

B-61 Yaltkaya, E. R., Enustun, B. V., Urkan, S., Senturk, H. S. and Korksal, K., "Non-Destructive Estimation of Cement Content of Hardened Concrete, <u>Minerals Processing</u>, Vol 6, No. 2, Feb 1965, pp 19-21.

Method of estimating cement content of concrete sample is based on determination of water of hydration of cement in powdered and oven-dried concrete samples by neutron moderation; cement content is computed on assumption that percentage of water of hydration is effectively constant for all cements; comparison of estimated and actual values shows reproducibility of method is satisfactory; there is small systematic error in method probably because of imperfect moisture stability.

B-62 Pochtovik, G. Y. and Kashkin, S. K., "Ultrasonic Measurements on Concrete Surfaces (Ultrazvukove Izmereniya V Betonnykh Pokrytiyakh), Report No. Trans-536, Mar 1965, Bureau of Reclamation, Denver, Colo.

Nondestructive testing of concrete surfaces under construction or already in use is possible by using an improved ultrasonic impulse method. This method may be used to control increased durability of concrete during construction, determine the actual durability of concrete at any place on the surface and compare it with control specimens, and determine and outline defective portions of pavement damaged by high temperatures generated by jet engines or by alternate freezing and thawing. The new method determines the velocity of longitudinal ultrasonic waves in a concrete slab and from this the durability of the conrete.

B-63 Vluchakis, S. D., "The Density Measurement of Concrete Road Surfacings by Means of Radioactive Isotopes," <u>Beton-Herstellung-Verwendung</u>, Germany, Vol 15, No. 7, Jul 1965, pp 303-305.

In recent years the range of application of methods for the nondestructive testing of concrete have been greatly extended. The author deals in his contribution with the method

of density measurement by means of radioactive isotopes and, on the basis of test results, shows that the crude density of fresh and hardened concrete can be determined from the surface with an accuracy of 2 percent without the destruction of the test specimen.

B-64 Thornton, H. T., "Soniscope Survey, Pad 39-A, Cape Kennedy, Fla.," Miscellaneous Paper No. 6-760, Nov 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Soniscope tests were conducted on concrete of pad 39-A at Cape Kennedy, Florida, to determine whether cracks present in the concrete were caused by placement of inferior quality concrete or by stresses imposed on normally good concrete. Compressive strength and pulse velocity tests were also conducted on 6- by 12-in. concrete cylinders made from a mixture comparable to that used in pad 39-A to aid in determining the quality of the concrete.

The tests revealed that the concrete is of generally good to excellent quality and that the cracking was caused by stresses of an undetermined nature.

B-65 Brachet, M. and Chevrier, J. P., "Measuring the Density of Concrete by Radioactivity," Silicates (Brussels), Vol 31, No. 1, pp 31-34, 1965.

A review of the instrumentation, the range of use, and accuracy of various radioactive procedures for determining the H_2O content of *d* of concrete, with special reference to the presence of materials (e.g., SiO_2, $CaCO_3$, H_2O) similar to those involved in the composition of the concrete and occurring naturally in the soil. It is considered that the homogeneity of blocks and beams is controllable with high accuracy by a method based on direct radiation, and that by preliminary calibration it is possible to determine mean *d* if the diffusion procedure is used and many measurements are made.

1966

B-66 Thornton, H. T., "Soniscope Investigation of Prestressed Concrete Piling, South Bulkhead, Manasquan Inlet, Manasquan River, N. J.," Miscellaneous Paper No. 6-793, Feb 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Prestressed pretensioned concrete sheet piling was used to form a part of the south bulkhead at Manasquan Inlet, Manasquan River, New Jersey. It was thought that excessive driving required for some of the piles might have resulted in damage to the concrete. A soniscope investigation was performed on the exposed portion of 14 of the piles in an attempt to determine if and to what extent the piling was damaged. Sixteen stations were located on each pile, and readings were taken straight through and diagonally through the concrete.

A combination of factors involved in the investigation has made the interpretation of data obtained very difficult. The limitation of being able to test only the exposed portion of the pile, the presence and influence of reinforcing steel, the fact that velocity varies with path length as well as with concrete strength, and the fact that the piles were prestressed have all hampered the interpretation.

Within the limits and capabilities of the test equipment, no significant anomalies were found that would indicate severely damaged or poor quality concrete in the piling. The relation between velocity and number of hammer blows suggests that some type of general, though no doubt minor, deterioration occurred during driving.

B-67 Pace, C. M. and Thornton, H. T., Jr., "Evaluation of the Soniscope for Nondestructive Testing of Portland-Cement Concrete Pavements," Miscellaneous Paper No. 6-806, Mar 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The report presents the results obtained from the soniscope instrument for use in the nondestructive testing of portland-cement concrete pavements. Essentially, the instrument was tested to determine if consistent velocity measurements could be obtained with the transducers in a position vertical on the prestressed, reinforced, and plain concrete pavements. Also of interest during the investigation was

the maximum distance through portland-cement concrete for which consistent velocity measurements could be obtained.

B-68 Skramtaev, B. G. and Leshchinsky, M. Y., "Complex Methods of Nondestructive Tests of Concrete in Constructions and Structural Works," RILEM Bulletin, No. 30, pp 99-105, Mar 1966.

Analysis of nondestructive methods were made and it was established that they can give considerable errors; it was shown that one way to increase accuracy and reliability for determining strength of concrete in structures is use of complex nondestructive methods; article contains suggestions for selecting methods of complex testing.

B-69 Preiss, K., "Measuring the Thickness of a Concrete Slab by Gamma Ray Transmission," Proceedings, American Concrete Institute, Vol 63, Jul 1966, pp 743-748.

Describes a method for determining the thickness of a concrete slab by measuring the amount of gamma radiation that passes through it. Results in the laboratory showed that slabs could be measured to an accuracy of better than 2 percent.

B-70 Muenow, R. A., "Nondestructive Testing of Structural Members," Public Works, Vol 97, No. 11, Nov 1966, pp 62-65.

Description of concrete test results carried out with ultrasonic transducers; curves are plotted to show early age testing results; to determine compressive strength, most accurate method is use of correlation between destructive testing and veloctiy measurements; structural analysis of bridge decks; determination of concrete thickness by ultrasonic resonance.

B-71 Whitehurst, E. A., "Evaluation of Concrete Properties from Sonic Tests," Monograph No. 2, 1966, American Concrete Institute.

Comprehensive review of origin and development of sonic test methods; use of sonic test results in direct calculation of dynamic moduli of elasticity and rigidity, and dynamic Poisson's ratio; sonic methods of evaluation of static modulus of elasticity, compressive and flexural strength, setting and creep characteristics, uniformity, cracking and general quality; equipment and techniques are described; it is concluded that sonic tests probably will not replace any other test method for concrete, but in some instances will reduce number of other tests required.

1967

B-72 McCoy, E. E. and Thornton, H. T., Jr., "Investigation of Soniscope Testing Procedure," Miscellaneous Paper No. 6-873, Jan 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Tests made to investigate apparent anomalies and discrepancies between results obtained with two types of instruments used for determination of ultrasonic pulse velocity in concrete, at Army Engineer Waterways Experiment Station, are made.

B-73 Thornton, H. T., Jr., "Field Soniscope Tests of Concrete," Technical Memorandum No. 6-383, Mar 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Results of soniscope measurements of ultrasonic pulse velocity made during 10-yr period at several test stations in concrete portions of four dams, one lock, and on 92 concrete specimens at field exposure station established in Georgia; measurements are used for evaluating changes that have taken place in concrete and for long-range evaluation of soniscope as device for nondestructive testing of concrete structures.

B-74 Galan, A., "Estimate of Concrete Strength by Ultrasonic Pulse Velocity and Damping Constant," Proceedings, American Concrete Institute, Journal, Vol 64, No. 10, Oct 1967, pp 678-84.

By means of regression analysis it is shown how ultrasonic pulse velocity and ultrasonic pulse damping constant can be used to estimate strength of concrete; two-parameter regression equation is most applicable when specimens are tested at their early stage of hardening or in a water saturated condition, and also at a specified time when the specimen is in a hardened state.

B-75 American Concrete Institute Committee 437, "Strength Evaluation of Existing Concrete Buildings," Proceedings, American Concrete Institute, Journal, Vol 64, No. 11, Nov 1967.

Strength of existing concrete buildings may be evaluated either analytically or by static load tests. These recommendations indicate when such an evalution may be needed, establish criteria for selecting the evaluation method, and indicate the data and conditions necessary for conducting either type of evaluation. Methods of determining concrete and steel properties used in the analytical investigation are described. It is recommended that theoretical analysis follow principles of ultimate strength design outlined in ACI 318-63, and that a structure be considered satisfactory if load factors and deflections satisfy requirements of ACI 318-63. Procedures for conducting static load tests are prescribed, and criteria are established for deflection and recovery of the structure being evaluated.

1968

B-76 Rajagopalan, P. R. and Chandra, P., "Ultrasonic Testing of Concrete-Correlation Between Pulse Velocity and Compressive Strength Under Field Conditions," Indian Concrete Journal (Bombay), Vol 42, No. 1, Jan 1968, pp 18-20.

Study to establish correlation between ultrasonic pulse velocity and compressive strength of concrete; paper presents

data obtained considering certain main variables which occur under field conditions, and indicates reasons why correlation could not be obtained under certain conditions; effect of voids on pulse velocities is reported.

B-77 Kondo, O. and Makita, M., "Non-Destructive Testing of Pavements Using Radioisotopes," Jul 1968, Public Works Res. Inst, CM/Japan.

A radioisotope will be used to measure the densities of each layer of a concrete or asphalt slab model for surveying methods for foundation and rock, roadbed, road foundation, and pavement slab.

B-78 ACI Committee 201, "Guide for Making a Condition Survey of Concrete in Service," Proceedings, American Concrete Institute, Journal, Vol 65, No. 11, Nov 1968.

This guide provides a system for reporting on the condition of concrete in service. It includes a check list of the many details to be considered in making a report, and provides standard definitions of 40 terms associated with the durability of concrete. Its purpose is to establish a uniform system for evaluating the condition of concrete.

B-79 Hughes, B. P. and Gregory, R., "Impact Strength of Concrete Using Green's Ballistic Pendulum," Proceedings, Institution of Civil Engineers (London), Vol 41, Dec 1968, pp 731-750.

An extensive investigation has been carried out using the impact test developed by Green. It is shown that this test can give very consistent results if the average energy per blow to "no-rebound" is used as the criterion for the impact strength of concrete.

The effects of varying the mix proportions, by changing the c/w ratio, cement content and coarse/fine aggregate ratio, on impact strength were investigated. The effects of four types of coarse aggregate, different maximum sizes of aggregate, different ages, and two types of cement were also

considered. The results, in general, indicated a remarkable correlation between impact strength and uniaxial (static) compressive strenth.

B-80 Kriegh, J. D. and Nordby, G. M., "Methods of Evaluation of Epoxy Compounds Used for Bonding Concrete, American Concrete Institute Publication SP-21, Paper No. SP 21-11, 1968, pp 107-118.

Test methods for evaluating epoxy compounds used for bonding concrete are discussed. Details of the flexural beam test, the double vertical shear test, the shear bond test, and the composite-cylinder test are described. Emphasis is placed on the composite-cylinder test, with performance results illustrated to show how it can be used as a material-acceptance test and for formulation studies and bonding techniques. Recommendations are made for use and development of this test procedure as a standard.

B-81 Malhotra, V. M., "Nondestructive Methods for Testing Concrete," Mines Branch Monograph 875, 1968, Department of Energy, Mines and Resources, Ottawa, Ontario, Canada.

This monograph deals with nondestructive methods for testing concrete. The tests considered are based on (1) surface hardness, (2) dynamic, and (3) radioactive methods.

Different methods of hardness testing are briefly mentioned and the Schmidt test hammer, based on the rebound principle, is described in detail. The calibrating procedure for the hammer is given and the test data published by various researchers are included.

Dynamic tests utilizing resonant frequency, mechanical sonic, and ultrasonic pulse velocity are described in detail. The test equipment and the test procedures for these methods are outlined and their various applications and limitations are discussed.

A radioactive test method employing x-ray penetration tests is briefly mentioned. The principle of gamma radiography is given and some of its applications are described.

The monograph concludes with a list of 81 pertinent references.

1969

B-82 Jones, R. and Facaoaru, I., "Recommendations for Testing Concrete by Ultrasonic Pulse Method," Materiaux et Constructions (Materials and Structures), Vol 2, No. 10, Jul-Aug 1969, pp 275-284.

Recommendations deal with the application of method to derive the elastic properties, strength and homogeneity of structural concrete, and for locating internal defects. Methods of measuring the pulse velocity, and the influence of test conditions on the accuracy of the measurements are discussed. Interpretational difficulties associated with the derivation of elastic properties and strength from in situ measurements of pulse velocity are given, and methods are recommended for overcoming these difficulties.

B-83 Larson, T. D., Cady, P. D., Browne, F. P., Carrier, R. E., and Lowry, L. L., "Durability Studies of Structural and Paving Concrete," Report No. SR-2, Sep 1969, Department of Civil Engineering, Pennsylvania State University, University Park, Pa.

A report is given of a two-yr research project on methods for analysis of hardened concrete. The major effort was directed toward improvement of the linear traverse technique. This included development of an automatic void sensing device to improve the speed and reliability of readings, development of data acquisition facilities and computer programs to accommodate the higher speeds and to eliminate a previous bottleneck in data reduction, and evaluation of statistical techniques to reduce the length of traverse needed. Another major contribution was the development and testing of a simple, inexpensive gage for determining the effectiveness of concrete curing procedures in the field. Pilot studies on a hypothesized deicer scaling mechanism and a technique for evaluating moisture distribution in concrete pavement slabs were also carried out.

B-84 Visvesvaraya, H. C., Desayi, P., Thomas, G., and Srinivasan, T. R., "Nondestructive Methods of Testing Concrete," Review Report RR-2-69,

Dec 1969, Research Institute of India, New Delhi.

Presents a review of existing knowledge and a comprehensive bibliography (682 entries) of nondestructive methods of testing concrete.

B-85 Bhargava, J., "Nuclear and Radiographic Methods for the Study of Concrete," Circular 60, 1969, Acta Polytechnica Scandinavica-Civil Engineering and Building Construction Service, Stockholm, Sweden.

Study of the factors which influence properties of concrete cast in deep forms. Sedimentation of concrete in columns was studied by γ-ray transmission method. Variation in moisture content along the height was studied by a neutron moisture gage, and distribution of cement was checked by tracer analysis. Zones of varying density and water content were observed in the columns. Structure of concrete was studied by penetrant dyes and by contact radiography of thin slices. Microcracks were found in concrete before loading. Relation between the strength and structure of concrete is critically reviewed.

B-86 Iddings, F. A., Arhan, A., Perez, A. W., II, Kiesel, D. W., and Woods, J. W., "Nuclear Techniques for Cement Determination," Highway Research Record No. 268, pp 118-130, 1969, Highway Research Board.

Several nuclear techniques for the determination of cement content in soil-cement and concrete have been studied. Activation analysis appears to offer some promise, either through the determination of calcium (formation of radioactive CA^{49}) or through the determination of silicon (formation of Al^{28}). The CA^{49} measurement utilizes thermal neutron activation while Al^{28} requires high-energy neutrons. Either measuring technique is rapid and simple, but that for calcium is more direct and reproducible. Determination of calcium can be completed in less than 15 min, and determination of silicon can be made in about 5 min. Both techniques adapt to field use. Selection of the technique would be influenced greatly by the aggregate used; e.g., calcareous aggregate would necessitate silicon determination.

Addition of a stable tracer, measurement of natural radioisotope content, and isotope dilution do not appear to be as applicable as activation analysis. However, under special circumstances, these techniques may be useful.

Measurement of natural radioactive content offers a simple approach to determination of cement content. This technique is slow compared with most radioisotope procedures, but is faster than chemical methods. This technique should be applicalbe to concrete already in place as well as core samples or ready-to-cast mixtures. Although probably more useful in some localities than in others, the technique should be widely applicable and simple to use.

<u>1970</u>

B-87 Moore, W. M., Swift, G., and Milberger, L. J., "An Instrument for Detecting Delamination in Concrete Bridge Decks," Research Report No. 130-4, Aug 1970, Texas Transportation Institute, Texas A & M University.

Describes some of the methods employed for delamination detection, the development of the basic components required for automatic detection, and the completed instrument resulting from the research. Evaluation tests indicate that the instrument provides a practical and effective means for the routine detection of bridge deck delamination by maintenance personnel. The instrument was found to be insensitive to deck texture or to thin asphaltic surfacing layers.

B-88 Muthukumaraswamy, A., "Strength Evaluation of Reinforced Concrete Bridge Decks by Non-Destructive Tests," <u>Indian Concrete Journal</u> (Bombay), Vol 44, No. 9, Sep 1970, pp 408-410.

In India, centerings for bridge decks are removed generally twenty-eight days after concreting, and in no case before twenty-one days. However, there have been occasions when, due to accident or floods, the centering gets disturbed prematurely, and the strength of the structure is called into question. Non-destructive tests were conducted in two cases and the ability of the structure to carry the design loads was established. The paper describes in detail the method adopted to evaluate the strength of the bridges.

B-89 Burt, J. O., Jr. and Rushing, H. B., "Non-Destructive Testing of Concrete," PB-204-372, Nov 1970, Louisiana Department of Highways.

Project evaluated performance of an ultrasonic testing device in predicting compressive strengths from tests performed on fresh concrete samples leading to the conclusion that further investigation with present available equipment was unwarranted.

B-90 Di Cocco, J. B. and Nuzzo, W. W., "Sonic and Conventional Measurement of Rigid Pavement Thicknesses," Report No. RR-69-12, Dec 1970, New York State Department of Transportation, Albany Engineering Research and Development Bureau.

On two paving projects, slab thickness was measured at 25 test locations by coring and by an ultrasonic method, and the results compared for precision. First, the difference between the thickness was determined and compared for each test location. Then, all measurements obtained by each method were grouped and compared for each project. The first comparison showed that differences can be large and may occur often, but nothing could be concluded about relative precision.

<u>1971</u>

B-91 Copen, M. D. and Wallace, G. B., "Determination of In Situ Stresses in Concrete Dams," <u>Proceedings, American Society of Civil Engineers</u>, Vol 97, No. PO2, Mar 1971, pp 455-473.

The in situ stresses within three concrete dams on the Salt River above Phoenix were determined by application of a three-directional borehole deformation gage. Two of the dams showed some signs of deterioration and structural cracking due to alkali aggregate reaction, thus requiring stress determinations for safety evaluation. Information on in situ stresses in the other dam was needed for design of expanded power facilties. The stress relief method, its verification tests and applications are examined. Best results for three-dimensional stress analyses are obtained if the drill holes are orthogonal, however, a technique is presented for

evaluating reliability of results obtained from having various orientations. The resulting stresses from the stress relief tests are compared with those computed by the trial load method. Maximum water surface and minimum concrete temperatures were the loading criteria for both methods. The 6-in. overcores were tested in the laboratory to determine the ability of the concrete to resist the in situ stresses.

B-92 Tassios, T. and Oeconomou, C., "Contribution to the Gamma Radiography of Reinforced Concrete Structures," Material Construction, Material Structure, Vol 4, No. 20, Mar-Apr 1971, pp 101-106.

New proposal concerning auxiliary techniques in gamma-radiography was investigated. Photometric measurements on simple gamma-radiographies were applied to estimate the diameter of an embedded bar, on the basis of the difference in film density, between the image of the bar and its surrounding area. Ordinary photogrammetric apparatus was used on twin stereoradiographies for direct discrimination of complicated bars of concrete reinforcements.

B-93 Elvery, R. H., "Non-Destructive Testing of Concrete and Its Relationship to Specifications," Concrete (London), Vol 5, No. 5, May 1971, pp 137-141.

Literature review on the non-destructive testing methods currently available for checking concrete at various stages of its manufacture and for assessing the quality of the end product. The paper suggests lines of approach for incorporating these methods in future specifications.

B-94 Preiss, K., "Checking of Cast-in-Place Concrete Piles by Nuclear Radiation Methods," British Journal of Non-Destructive Testing, Vol 13, No. 3, May 1971, pp 70-76.

This paper describes the use of gamma ray transmission and neutron backscattering methods to check that the concrete is correctly cast. The gamma ray transmission method is

usually preferred, and the effects of various parameters on the accuracy of this method are evaluated.

B-95 Levitt, M., "Non-Destructive Test for the Durability of Concrete," British Journal of Non-Destructive Testing, Vol 13, No. 4, Jul 1971, pp 106-112.

The Initial Surface Absorption Test (ISAT) is discussed from the points of view of what is required of concrete in practice and what is needed in a test method. The historical development of the test is described and the mechanism of the passage of water into a permeable material is formulated. It is shown that the test is simple and direct in its approach, relatively easy to undertake and generally relates to the performance of concrete on site.

B-96 Mailer, H., Golis, M. J., McMaster, R. C., and Raab, T. J., "The Development of Ultrasonic Nondestructive Testing Instrumentation to Measure Pavement Thickness," Jul 1971, Engineering Experiment Station, Ohio State University.

The objective of this research program was the development of ultrasonic instrumentation to measure the thickness of concrete pavements. As a results of this research, an instrument has been developed which can measure the thickness of portland cement concrete to within ± 2 percent under laboratory conditions. Preliminary field test data suggest that this instrument is capable of the same accuracy on highway pavements. A complete field evaluation, however, will have to be conducted before a definite statement can be made regarding the accuracy of the gage under field conditions.

A laboratory investigation was also conducted to evaluate the capability of this instrument to measure the thickness of plastic concrete pavements. If this instrument could measure the thickness of concrete immediately after placing, it could be used to monitor, and control, the laying of pavements by a slipform paver. The results of this study, however, showed that this instrument could not measure concrete thickness immediately after placing. An analysis of the results also indicated that it was unlikely that any acoustic technique could perform this function.

The research objective and the pavement thickness gage system are briefly discussed in Section I. The important fundamental studies of the acoustic properties of concrete which led to the particular design of the thickness gage are presented in Section II. The research concerned with the thickness measurement of plastic concrete is also reported in this section. Section III deals with the final development of the gage system. The results of the performance of the gage, both in the laboratory and in preliminary field testing, are also presented. The detailed design of the gage system is given in Appendix A. Instructions for the operation of the thickness gage are presented in Appendix B. Acoustic velocity measuring techniques are discussed in Appendix C. The theory of the acoustic radiation pattern from the gage transmitter is presented in Appendix D. The results of the tests which led to the final design of the transmitter are presented in Appendix E.

B-97 Bhargava, J., "Application of Some Nuclear and Radiographic Methods on Concrete," Material Construction, Material Structure, Vol 4, No. 22, Jul-Aug 1971, pp 231-240.

Gamma-ray transmission method was used for studying the variation in density of concrete caused by settling in columns. Moisture content of concrete was determined by the neutron scattering technique and the distribution of cement was studied by radioactive tracer analysis. The structure of concrete was studied by radiographing thin slices of concrete. Formation and propagation of cracks was studied from radiographs taken at regular intervals.

B-98 "Nuclear Techniques for Cement Determination," Modern Concrete, Aug 1971, p 39.

Discussion of preliminary report of a two-year research project being conducted by the Nuclear Science Center of the University of Louisiana. Project is investigating the application of nuclear science techniques to measure the amount of cement in concrete and cement-soil mixtures.

B-99 "Board of Standards Approves Windsor Probe as Alternative for Cores," Concrete Industry Bulletin, Aug 1971, pp 13-19.

New York City's Board of Standards and Appeals approves the Windsor Probe as an alternative for core testing in the city of New York, as a non-destructive test method for determining the compressive strength of concrete in place.

B-100 Dudderar, T. D. and O'Reagan, R., "Laser Holography and Interferometry in Materials Research," Materials Research and Standards, Sep 1971, pp 8-15.

Description of laser holography and its application to interferometry in materials research and nondestructive testing. Holography and interferometry are combined into a new optical measuring technique for the quantitative evaluation of the material response to applied mechanical or thermal loading, the nondestructive detection of small flaws or cracks, and the identification of a critical accumulation of fatigue damage. With the technique, information about either initial geometry or deformation under load can be obtained from test specimens which are too complex to be studied by other methods.

B-101 Cullington, D. W. and Mayfield, B., "The Apparatus and Instrumentation for an Investigation of the Strains in Mass Concrete Due to Fluid Pore Pressure," Magazine of Concrete Research, Dec 1971, pp 181-186.

Description of apparatus and instrumentation used to investigate effects of triaxial stresses, including pore pressure, upon mass concrete.

B-102 Lepper, H. A., Jr. and Rodgers, R. B., "Nuclear Methods for Determining the Water Content and Unit Weight of Fresh Concrete," Journal of Materials, Dec 1971, pp 826-841.

Neutron radiation used to determine quantity of water present in samples of standard shape and size. Gamma radiation used to measure unit weights of samples of sand, gravel, cement, and concrete of the same dimensions. High degrees of correlation found for materials and for unit weights, from about 95 to 150 pounds per cubic foot.

B-103 MacLeod, G., "An Assessment of Two Nondestructive Techniques as a Means of Examining the Quality and Variability of Concrete in Structures," Technical Report 42-454, 1971, Cement and Concrete Association, London.

The results of two series of tests, conducted with the aim of comparing the characteristic compressive strength of in situ concrete columns with that of laboratory-cured cubes and cylinders prepared in conjunction with the columns are presented as a first state in the assessment of the partial safety factor for concrete strength, γm, as defined in the draft Code of Practice for the Structural Use of Concrete. Nondestructive techniques of pulse velocity and rebound index were used for predicting the in situ characteristic strength.

It is concluded that a reasonable empirical assessment of γm by nondestructive techniques is possible, although some difficulty is experienced with deep members cast from mixes of low cohesion. The test results indicate a need for the adoption, in addition to γm, of a quality acceptance factor, γp, expressing the ratio of characteristic pulse velocity in the laboratory-cured specimens to that in the member at a particular time after casting.

B-104 Tabikh, A. A., Balchunas, M. J., and Schaffer, R. K., "A Method Used to Determine Cement Content in Concrete," Highway Research Record No. 370, pp 1-35, 1971, Highway Research Board.

The cement content in hardened concrete must frequently be determined in order to rebut those who tend to blame the cement whenever the concrete does not meet specifications. Although cement failure is indeed a significant factor, other factors that are often overlooked can be equally important. Thus, a method is needed for determining the cement content of hardened concrete so that the possibility of

cement failure can be eliminated and other parameters can be examined. Existing methods, which are handicapped by inconvenience, error, or expense, lack the requirements to meet this need.

The standard ASTM Method C 85 (Test for Cement Content in Hardened Portland Cement Concrete), although tedious, usually gives reliable results when information concerning both the cement and the aggregate is available. Kossivas has proposed an alternate method in which the sulfate ion content is determined. However, to obtain a satisfactory cement determination requires that the sulfate content of the cement be known, and that all the sulfates be derived from the cement. The authors have found aggregates, in a number of instances, that contain sulfates in sufficient quantities to cause serious errors.

Some instrumental methods based on neutron activation and isotopic measurement techniques have been used for cement determinations. These nuclear methods have been used primarily for field measurements. However, errors caused by common elements exist, as in the previously mentioned methods. Another deterrent is the high cost of equipment.

The method presented in this study is intended to satisfy the need for a method to determine the cement content of hardened concrete and to circumvent the difficulties discussed in existing methods. No prior knowledge of the chemical composition of either the cement or the aggregate is required. The suggested method involves an extraction of the concrete sample with a methanolic solution of maleic acid.

In a previous study, maleic acid was used to extract the silicates from portland cement. Subsequently, it was established that all hydration products are soluble in maleic acid. Because the ideal method of determining cement content in concrete would involve a solution of the cement only, maleic acid extraction seemed a plausible approach. This has in fact been confirmed by a study in which a variety of aggregates were extracted by using an alcoholic solution of maleic acid. In no case was aggregate weight loss observed.

1972

B-105 Arni, H. T., "Impact and Penetration Tests of Portland Cement Concrete," FHWA-D-73-5, Feb 1972, Materials Division, Federal Highway Admistration, Washington, D. C.

Tests using the Swiss Rebound Hammer and Windsor Probe Test System were made on concrete slabs and cylinders made with three coarse aggregates, one mortar, two maximum sizes of aggregate, and at four ages, and were compared with compressive strength tests on the cylinders. The general conclusions were that, although both rebound and probe measurements show a correlation with compressive strength, neither test provides a precise determination of strength. Either one can be used to assess relative quality in different concretes or different areas of the same concrete, to survey a concrete surface to find areas of poor quality or of deteriorated concrete, and to determine when it is safe to remove forms. For any of the uses to which both can be put, the Swiss hammer has an advantage because of the larger number of tests that can be made on a given area, lower cost per test, and nondestructiveness.

B-106 Russell, J. E., Gnirk, P. F., and Oliver, T. K., "Nondestructive Determination of Pavement Thickness Using Electrical Resistivity Techniques," Apr 1972, South Dakota School of Mines and Technology, Rapid City.

Electrical resistivity techniques used to test both cured and freshly placed concrete pavement thicknesses; model found approximately correct for fresh concrete but inadequate for cured.

B-107 Figg, J. W., "Determining the Water Content of Concrete Panels by Using a Microwave Moisture Meter," <u>Magazine of Concrete Research</u>, Vol 24, No. 79, Jun 1972, pp 93-96.

Sections of 1 x 2 m, sawn from full-size commercial concrete panels, were tested with a microwave moisture meter to establish calibration curves for different types of concrete cladding panel. The tests confirmed that the relationship between microwave attenuation and percentage of absorbed water for such panels was linear, but it was also found that the slope of the curve depended upon the particular construction of the concrete panel. With 10 percent absorbed water, the microwave attenuation varied between approximately 10 and 20 dB.

B-108 Elvery, R. H., "Ultrasonic Testing of Concrete: The Use of the V Meter," Jul 1972, James Electronics, Inc., Chicago, Ill.

The paper discusses both the theoretical basis and practical application of nondestructive ultrasonic testing to concrete structures. Among the data presented are curves relating pulse velocity to dynamic and static modulus of elasticity; determination of crack depth; the influence of steel reinforcement bars on measured pulse velocity; typical distribution of pulse velocity across badly compacted reinforced beams; early age development of pulse velocity in concrete; the relationship of ultrasonic pulse velocity to firing temperature and residual strength after fire damage; and typical strength-pulse velocity correlation.

B-109 Reijonen, H. and Pihlajavaara, S. E., "On the Determination by Neutron Radiography of the Thickness of the Carbonated Layer of Concrete Based upon Changes in Water Content," Cement and Concrete Research, Sep 1972, pp 607-615.

Gives description of application of neutron radiography to detection of water changes in concrete. As attenuation of thermal neutrons in concrete is mainly attributable to interactions with hydrogen, even modest changes in water content, such as those associated with carbonation, are observable.

B-110 Balakrishna Rao, H. A. and Harnage, D., "Evaluation of Rigid Pavements by Nondestructive Tests," Highway Research Record No. 407, pp 76-86, 1972, Highway Research Board.

This paper presents a vibratory nondestructive evaluation procedure as applied to rigid pavements. It is restricted, however, to a comparison between a measured deflection field around a loaded plate and a predicted deflection field obtained by using elastic properties of layers (gathered by nondestructive tests) in a radial symmetric finite-element program on a test section. Because these two deflection fields do not agree in their magnitudes due to the low strain level created by the vibrator during the determination of the

elastic properties of the layers, two methods to correct the modulus of the subgrade material (determined by low-intensity vibration tests) were investigated. The first method uses the information obtained by a plate load test; the second method uses laboratory repeated load tests results (developed by the University of Kentucky). These methods were applied in a simplified form to a test section. By utilizing the finite-element method, the predicted deflection field with the corrected modulus was compared with the measured deflection field. Further studies required to make this evaluation procedure a useful tool in solving practical problems are outlined.

B-111 "Non-Destructive Testing of Concrete," Highway Research Record No. 378, 1972, Highway Research Board.

Seven reports are given under the headings: Advances in nondestructive testing of concrete; nondestructive testing of concrete by wave velocity methods, a laboratory and field study; pavement thickness measurement using ultrasonic techniques; investigation of applicability of acoustic pulse velocity measurements to evaluation of quality of concrete in decks; noncontact measurements of foundations and pavements with swept-frequency radar; field investigation of concentration tests of portland cement concrete.

B-112 Brownfield, W. E., "Non-Destructive Testing of Concrete by Wave Velocity Methods: A Laboratory and Field Study," Highway Research Record No. 378, pp 12-19, 1972, Highway Research Board.

An investigation was conducted to determine whether the compressive strength and modulus of elasticity of concrete could be determined from the velocity of an elastic compression wave traveling through it. Two comparisons between seismic velocities and elastic wave velocities, and elastic wave velocities determined by the soniscope method are presented. A correlation between the seismic velocity and compressive strength of slabs and beams constructed of concrete containing San Gabriel drainage aggregate was developed.

B-113 Duffy, D., "Concrete Analysis by Neutron-Capture Gamma Rays Using Californium 252," Highway Research Record No. 412, pp 13-24, 1972, Highway Research Board.

The feasibility of analyzing concrete and cement by a measurement of the neutron-capture of prompt gamma rays was investigated; a 100-μg californium-252 source was used to supply the neutrons. A lithium drifted germanium crystal detected the capture gamma rays emitted. The capture gamma rays from cement, sand, and coarse aggregates of quartizite gravel, limestone, and diabase were studied. Concrete blocks made from these materials were tested.

B-114 Li, S., Ramakrishnan, V., and Russell, J. E., "Advances in Nondestructive Testing of Concrete," Highway Research Record No. 378, pp 1-11, 1972, Highway Research Board.

Review of modern advances in the ultrasonic, resonance, radioactive, electrical, initial surface absorption, chemical analysis, and hardness methods of testing concrete is made. The research work in progress at the South Dakota School of Mines and Technology is described.

B-115 Lundien, F. R., "Noncontact Measurements of Foundations and Pavements with Swept-Frequency Radar," Highway Research Record No. 378, pp 40-49, 1972, Highway Research Board.

Analytical methods were developed to extract values for the electrical properties and layer thicknesses from the reflectance curves. Methods are demonstrated on theoretical reflectance curves from profiles of an asphalt highway and a concrete highway. Swept-frequency radar measurements from either an air platform or a land vehicle show promise for reducing both costs and time in the testing of old construction foundations and in the control of new construction.

B-116 "Optimization of Density and Moisture Content Measurements by Nuclear Methods," Report 125, 1972, National Cooperative Highway Research Program.

National Cooperative Highway Research Program report presents analysis under headings "gamma-ray gages for measuring soil density," and "neutron gages for measuring soil moisture content," with three-part appendix. Findings are presented under headings: Identification and definition of errors, quality factor concept, optimization of the air-gap method; optimization of simple-detector, dual gages optimization of energy-discrimination, stringently collimated gages.

B-117 Swift, G. and Moore, W. M., "Investigation of Applicability of Acoustic Pulse Velocity Measurements to Evaluation of Quality of Concrete in Bridge Decks," Highway Research Record No. 378, pp 29-39, 1972, Highway Research Board.

The compressional wave velocity and several other significant properties of concrete specimens were determined in the laboratory by using a variety of concrete compositions. It was found that the measured velocity and the unit weight could be used to estimate the elastic modulus of the concrete as measured either by stress-strain observations or by resonant frequency testing.

1973

B-118 Nwokoye, D. N., "Prediction and Assessment of Concrete Properties From Pulse Velocity Tests," Magazine of Concrete Research, Vol 25, No. 82, Mar 1973, pp 39-46.

A study has been made of the feasibility of applying multi-phase theory to the interpretation of pulse-velocity tests. This included a general examination of certain non-destructive test parameters. It is suggested that multi-phase interpretation of pulse-velocity tests could be used to examine the property and behavior of mortars and of cement-paste phases in concretes.

B-119 Powers, J. and Collins, T. J., "Underwater Bridge Inspection," Civil Engineering, American Society of Civil Engineers, Vol 43, No. 3, Mar 1973, pp 66-68.

Historical records and recent engineering periodicals indicate that many bridge failures are related to foundation distress. A diving inspection is often the only means of detecting conditions that may lead to failure. Diving inspections are not only a safeguard against imminent bridge failure, but are also useful as a part of general bridge maintenance repair programs. In bridge rehabilitation projects, often the cost of a diving inspection is very small compared to the savings that can be realized. Points to remember in the underwater inspection of bridges are noted in this article.

B-120 Luxmoore, A., "Holographic Detection of Cracks in Concrete," Nondestructive Testing (Surrey), Vol 6, No. 5, Oct 1973, pp 258-263.

Nondestructive testing of concrete, although desirable, presents problems because of concrete's coarse heterogeneous structure. The author describes the application of holography to this problem and discusses the results so far achieved. Considerable effort is being expended on the development of pulse lasers that will freeze movement in the structures and also on electronic recording of the hologram information. Existing techniques can be used for a large variety of investigations, and some work has been carried out on artificially produced cracks in high-strength steels. The holographic results were compared with penetrating dyes, x-ray radiography, and eddy current testing and found to be just as reliable, although untempered martensite could produce anomalous fringe patterns.

B-121 Figg, J. W., "Methods of Measuring the Air and Water Permeability of Concrete," Magazine of Concrete Research, Vol 25, No. 85, Dec 1973, pp 213-219.

Describes a simple and portable apparatus for estimating the air and water permeability of concrete in situ. The methods used require a small hole 5.5 mm in diameter and 30 mm deep to be drilled in the specimen. The hole is plugged with a catalyzed liquid silicone rubber which sets to give a resilient seal to the small cavity in the concrete. A gas- and liquid-tight connection is obtained by inserting a hypodermic needle through the silicone rubber. The results obtained using the apparatus on laboratory-prepared concrete

show good correlation with both water-cement ratio and compressive strength; it is suggested that the proposed methods may prove useful for predicting the durability of concrete. The techniques are sensitive enough to detect differences in aggregate porosity. The moisture content of the concrete has a major influence on the readings; a miniaturized moisture meter is being developed so that corrections can be made for this effect.

B-122 Moore, W. A., "Detection of Bridge Deck Deterioration," Highway Research Record No. 451, pp 53-61, 1973, Highway Research Board.

Delamination is probably the most serious form of deterioration that is commonly found in bridge decks. It ultimately results in large scale spalling that necessitates costly repairs. This type of failure is believed to be caused chiefly from salt-induced corrosion of the reinforcing steel. An instrument designed to detect delamination and the validation tests is described. The instrument has been used by Texas Highway Department maintenance personnel and has been found to be an effective and practical tool, especially on resurfaced decks.

Other bridge deck evaluation techniques that are investigated are delamination, detection, corrosion potential, acoustic velocity, Windsor probe, Schmidt rebound hammer, and direct tensile strength. It appears that all of these techniques have considerable merit. It is believed that any of them can be used to search out weak spots or deterioration in bridge decks.

1974

B-123 Hageniers, O. L. and Csagoly, P., "Diffractographic Strain Gages for Use on Concrete Structures," Proceedings, American Concrete Institute, Journal, Vol 71, No. 1, Jan 1974, pp 41-44.

The capabilities of a newly developed diffractographic strain gage are discussed with emphasis on its applications on concrete structures. I's long-term stability and high accuracy make it particularly suitable for structural applications. The results of two long-term tests (11 months and 7 months), one on laboratory specimens and the other a field application, are used as verification of the gage's advantages.

B-124 Malhotra, V. M., "Evaluation of the Windsor Probe Test for Estimating Compressive Strength of Concrete," Materials and Structures, Research and Testing (Paris), Vol 7, No. 37, Jan-Feb 1974, pp 3-15.

Describes an investigation to evaluate the Windsor probe test for estimating compressive strength of concrete. Briefly, the probe test is performed by firing a 3.125 in. (82.6 mm) alloy-steel probe into the hardened concrete. The exposed probe length is recorded and is related to the compressive strength of concrete. The effect of the aggregate hardness is taken care of by using different calibration charts for minerals having different Mohs hardness. The results of a study to evaluate the compressive strength of 24- by 24- by 8-in. (61- by 61- by 20-cm) deep concrete slabs are given. The applications and limitations of the new test are discussed.

B-125 Luisoni, C. J. and Somenson, H. M., "Non-Destructive Test for Determining Compressive Strength," Proceedings, American Concrete Institute, Journal, Vol 71, No. 3, Mar 1974, pp 132-133.

The method presented and considered as nondestructive is based on the localized fracture of concrete under high compressive stresses applied to an extremely small area. This test does not destroy the structural element, but does destroy the material that is analyzed.

B-126 Nand, K., Desai, P. J., Marwadi, S. C., Wedpathak, A. V., and Guha, S. K., "Sonic Method for the Detection of Deep Cracks in Large Structures," The Indian Concrete Journal (Bombay), Vol 48, No. 3, Mar 1974, pp 98-102.

A simple but reliable sonic method for estimating the depth and extent of deep cracks in large structures such as dams has been developed at the Central Water and Power Research Station, Poona, and successfully employed for Bhandardara in Maharashtra, Konar in Bihar, and Idikki in Kerala. The method has also proved useful for assessing the efficacy of epoxy grouting used for treating the cracks in the above dams. The paper presents the basic principles and the experimental details of the sonic method, and the results obtained from the studies at the different dams.

B-127 Tomsett, H. N., "Nondestructive Testing of Floor Slabs," Concrete (London), Vol 8, No. 3, Mar 1974, pp 41-42.

The instrument used in the investigations is the Pundit (portable ultrasonic nondestructive digital indicating tester). This instrument measures transit times on a digital display of 3 digits which has two ranges and is capable of measuring from 0.1 to 999 microseconds in units of 0.1 microsecond. Three possible methods of applying the transducers to a piece of concrete under test are illustrated.

B-128 Houston, B. J., "Condition Survey of Lock and Dam 52, Ohio River," Miscellaneous Paper No. C-74-5, Apr 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

A program to conduct a condition survey of Lock and Dam 52, which is located on the Ohio River near Paducah, Kentucky, was authorized and funded by the U. S. Army Engineer District, Louisville, in June 1972. Lock and Dam 52 was constructed approximately 45 years ago. The purpose of this investigation was to determine the general condition of the structure in order that effective plans could be made to accommodate present and future river traffic. The U. S. Army Engineer Waterways Experiment Station (WES) was contracted to conduct a part of the investigation, including a crack survey, borehole camera studies in drilled holes, underwater television camera crack studies, and sonic studies of the structure. The Ohio River Division Laboratory (ORDL) conducted physical tests and a petrographic examination of drilled concrete cores. Results of ORDL's tests are also included in this report. The results of the investigations indicate that the concrete in the underwater sills, the piers, and the fixed weir is free from any deleterious chemical reactions. No silica-gel deposits, reaction rims, fractures, or other signs of distress due to alkali-aggregate reaction were found. Cracking of the concrete was extensive, but not excessive, and apparently can be attributed to such physical causes as freeze-thaw cycles of the exposed concrete, normal shrinkage, and foundation problems. A 4-in. separation was found between pier 1 and the underwater sill and excessive cracking was noted in the exposed concrete of piers 2 and 5. The cracking in piers 2 and 5, however, was not considered to be structurally damaging. Corrective action, however, appears advisable in regard to pier 1, especially to prevent the passage of water underneath the Chanoine Pass sill at this location.

B-129 Houston, B. J., "Condition Survey of Lock and Dam 53, Ohio River," Miscellaneous Paper C-74-7, May 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

A condition survey of Lock and Dam 53, which is located on the Ohio River between Paducah, Kentucky, and Cairo, Illinois, was authorized and funded by the U. S. Army Engineer District, Louisville, in April 1973. Lock and Dam 53 was constructed approximately 45 years ago, and the purpose of this investigation was to determine the general condition of the structure in order that effective plans could be made to accommodate present and future river traffic. The U. S. Army Engineer Waterways Experiment Station was requested to conduct a part of the investigation, including a crack survey, borehole camera studies in drilled holes, and sonic studies of the structure. The Ohio River Division Laboratory (ORDL) conducted physical tests and a petrographic examination of drilled concrete cores. Results of ORDL's tests are also included in this report. The results of the investigations indicate that the concrete in the underwater sills, the piers, and the fixed weir is dense, homogeneous concrete free from damage from cement-aggregate reaction, from sulfate attack, and from serious frost damage. Cracking of the concrete was extensive, but not excessive, and apparently can be attributed to physical causes such as freeze-thaw cycles of the exposed concrete, normal shrinkage, and minor foundation problems. Excessive cracking was found only in pier 2. The cracking in pier 2, however, is not considered to be structurally damaging.

B-130 Wheen, R. J., "Non-Destructive Testing of Concrete," Building Science, Vol 4, No. 4, Jul 1974, pp 669-681.

Literature review is presented on the many methods for the nondestructive testing of concrete. The methods are classified as surface methods, vibration and resonance methods and electrical and magnetic methods. The use of combinations of methods is seen as a significant development in the field. Other methods, some of which await exploitation, are discussed. It is concluded that unreasonable expectations for nondestructive test methods and lack of trained technicians to apply them are the main reasons for their slow acceptance.

B-131 "End 'Guesswork' Road Repairs," American City, Vol 89, No. 9, Sep 1974, pp 60-61.

The nondestructive testing device called the Road Rater is mounted on the front of a van. It induces deflection in the pavement and underlying subgrade which are recorded and can be used to prepare a picture of the roadway showing the strengths of various areas. Tests can be made every 200 ft for a quick survey or closer together for a more comprehensive survey.

1975

B-132 Kameda, H. and Koike, T., "Reliability Theory of Deteriorating Structures," Journal of the Structural Division, Proceedings, American Society of Civil Engineers, Vol 101, No. ST1, Jan 1975, pp 295-310.

A method of analysis of the reliablity for structures with resistance deterioration is developed. Random resistance of structures is assumed to deteriorate in proportion to the deterioration factor which is a function of the intensity of applied loads. In describing the survival of deteriorating structures, the nonfailure effect is also taken into consideration. Probability distribution of the residual resistance, failure rate, and reliability funciton for future loads are obtained for deteriorating structures with or without experiences of past loads of known intensities. Special cases of these results coincide with the classical reliability theory for repeated loads. Numerical results are obtained for the mean residual resistance, the failure rate, and the reliability function, from which it is concluded that the deterioration effect is important in the reliability theory for repeated loads and that the form of the deterioration factor has a great influence upon the analytical results.

B-133 Seals, R. K. and Anderson, D. A., "Application of Nondestructive Testing Techniques for Evaluation of Engineering Properties of Portland Cement Concrete," Final Report - Phase I and II, Research Project No. 37, Jan 1975, West Virginia Department of Highways.

The principal goals of the Phase I and Phase II studies were, respectively: (1) to establish the validity of predicting strength from nondestructive measurements and to select an optimum combination of sample configuration, test method, sample preparation technique for use in Phase II and III, and (2) to study the effects of aggregate type, water/cement ratio, and cement factor on the prediction of long-term strength from early-time pulse velocity measurements. On the basis of the Phase I test results it was recommended that future testing be limited to compressive strength, destructive and pulse velocity, nondestructive testing. Specimens should be prepared by rodding only. The Phase II results indicated, for a range of water/cement ratios, cement factors, and aggregate types, that pulse velocity at an early time (1 or 2 days) can predict compressive strength at later times (28 and 90 days) with reasonable accuracy and reliability. Aggregate type was found to produce a significant effect on the relationship between pulse velocity and strength. Although not studied extensively, air content, cement type, and maturity were also found to produce a significant effect on the pulse velocity-strength relationship.

B-134 Roethig, "Measuring Ultrasonic Attenuation in Concrete," Batiment International-Building Research and Practice, Vol 3, No. 1, Jan-Feb 1975, pp 24-31.

The author describes work on the calculation of friction and scatter attenuation in the ultrasonic testing of concrete. Ultrasonic attenuation is defined as the sum of all processes contributing to the weakening of a plane ultrasonic wave expanding in a medium of infinite dimensions and generated by the properties of the sound-conducting medium (concrete).

B-135 Ghosh, R. K. and Vigayaraghavan, S. R., "Estimation of the Cement Content of Hardened Concrete by a Nuclear Method," Indian Concrete Journal (Bombay), Vol 49, No. 4, Apr 1975, pp 102-110.

The paper suggests a nuclear technique for estimating the cement content of hardened concrete on the basis of the amount of hydrogen nuclei present in it. The general principles that are basic to the method are discussed, and then the suggested technique is described. The inaccuracies involved in the

estimation by using this technique and the corrections necessary to improve the degree of accuracy are analyzed. Laboratory tests indicate that the technique yields results with a good degree of accuracy.

B-136 Malhotra, V. M., "In-Place Evaluation of Concrete," Journal of the Construction Division, Proceedings, American Society of Civil Engineers, Vol 101, CO2, Jun 1975, pp 345-357.

The Windsor probe consists of a power-actuated gun or driver, hardened alloy probes, loaded cartridge, a depth gage for measuring penetration, and related equipment. A pullout test measures, with a dynamometer, the force required to pull out from concrete a specially shaped steel rod with an enlarged end that has been cast into that concrete. The pullout force is related to compressive strength, the ratio of the pullout-compression strength being between 0.1 and 0.2. The two new pieces of equipment which are either simplified versions of equipment already available or based upon well established theoretical concepts are: a lightweight portable ultrasonic concrete tester, and a meter which measures maturity of concrete by use of a probe.

B-137 Moore, K. R., "Rapid Measurement of Concrete Cover on Bridge Decks," Public Roads, Vol 39, No. 2, Sep 1975, pp 48-52.

Evaluation tools for testing concrete bridge decks and for determining the effectiveness of bridge deck protective systems are currently being studied by the Federal Highway Administration. One of these studies involves the development of a Rolling Pachometer that can be used for nondestructive determination of the cover over the reinforcing steel on concrete bridge decks. This unit is reported to be an effective tool for both inspection and quality control.

B-138 Rajagopalan, P. R. and Prakash, J., "Non-Destructive Testing of Pile Foundations," Indian Concrete Journal (Bombay), Vol 49, No. 12, Dec 1975, pp 363-365, and 377.

Cast-in-place pile foundations present a unique problem in nondestructive testing, since only the top of the foundation is accessible even though the entire depth of the foundation is required to be tested. The problem is particularly acute in the case of deep pile foundations. There is a need for a satisfactory nondestructive method of checking concrete in the foundation. Of the many methods available for nondestructive testing of concrete, the ultrasonic pulse method is one which affords the possibility of checking the foundation at any desired depth.

In the work reported in this paper, pipes 2.5 cm in diameter were embedded along the depth of the foundation while it was being cast. The transmitting and receiving probes were introduced into the pipes, and a fluid was used for acoustic coupling between the transducers and pipes. Laboratory tests were conducted by simulating defects which normally occur in the field. Pile foundations were constructed, in which different types of defects were introduced. From ultrasonic tests conducted on these foundations it was found that these tests could indicate the existence of defects and distinguish between the regions of good concrete and defective concrete. The method can be used for testing pile foundations up to 75 cm in diameter and 20 m in depth.

B-139 Van Daveer, J. R., "Techniques for Evaluating Reinforced Concrete Bridge Decks," <u>Proceedings, American Concrete Institute, Journal</u>, Dec 1975, pp 697-704.

Premature deterioration of reinforced concrete bridge decks has become a serious nationwide problem. Although a solution for the deterioration problem has not been found, there are several techniques available to identify the areas of concrete deterioration.

The major cause of deterioration is discussed and each evaluation technique is described. The results of a corrosion survey of 473 bridge decks and the interim results of a concrete cover survey are described.

B-140 Iddings, F. A., Arman, A., Pepper, C. E., Aubert, W. G., and Landry, J. R., "Determination of Cement in Concrete by Activation Analysis with Californium-252," Transporation Research Record No. 539, pp 20-26, 1975, Transporation Research Board.

Results from neutron activation analysis of in-place and plastic concrete samples are presented. Data were obtained by equipment suitable for and operated under field conditions. The system described for determination of cement content of in-place concrete includes a 35-microgram Cf-252 source, portable activation/shield assembly with remote operating cable, and commercially available detector and electronics. An analysis of in-place concrete is accomplished in 22 minutes. Results for plastic concrete were obtained with a system designed for soil-cement mixtures. Using a 140-microgram Cf-252 source, an analysis could be completed in 9 minutes with an accuracy of $\pm$ 5 percent of the amount of cement for normal cement contents. A system for analysis for samples of plastic concrete, cores, and soil-cement is described that can be moved to field sites in a trailer. Most existing methods for determination of cement content of concrete suffer because they are too slow, use too small a sample to be representative, and must be done in a laboratory. The only other field measurement technique being studied utilized low-energy photon scatter. This technique uses only a thin layer of the available sample and fails to achieve necessary accuracy when aggregate varies in size distribution or heavy element content. Neutron activation analysis offers a rapid, simple, field-operational procedure for measurement of cement content. Besides these advantages, activation analysis allows the use of large, representative samples and offers considerable freedom from interferences.

B-141 "Non-Destructive Testing of Concrete (Part IV)," Rapport 69, 1975, Netherlands Committee for Concrete Research (Zoetermeer).

Until recently, methods commonly employed for determining the compressive strength of concrete by nondestructive testing have consisted either in measuring the velocity of propagation of ultrasonic pulses or in determining the rebound number with a Schmidt rebound hammer. In applying both these methods it is essential at least to take curing conditions of the concrete into account or to allow for its moisture content at the time of testing and preferably to also allow for the composition of the concrete.

With the aid of laboratory tests it was shown that a much more accurate result can be derived for the compressive strength from the combination of the pulse velocity and the damping constant of the concrete. It is then moreover unnecessary to take account of the data relating to the composition or the moisture content of the concrete, provided

that sand and gravel are used as aggregate. This method, however, is not directly serviceable in actual practice, because damping constant can be measured only on specimens having a regular shape, such as prisms.

From laboratory tests it has also been established that the compressive strength can also be determined from the combination of the pulse velocity and the rebound number.

Although then somewhat less accurate, the two measurements involved can be performed simply and quickly on the building site. As for the accuracy of the value derived for the composite strength and/or the ease of measurement, this combination was found to be distinctly superior to three other combined methods that were investigated. Descriptions of the three combined methods are also included in the paper.

1976

B-142 Chhauda, J. N., "Non-Destructive Testing of Concrete by the Schmidt Rebound Hammer," Indian Concrete Journal (Bombay), Vol 50, No. 1, Jan 1976, p 19-20, and 28.

The paper describes the operation and calibration of the Schmidt type "N" rebound hammer at the Structural Engineering and Research Centre, Roorkee, India. The author stresses the necessity for formulating an Indian code of practice for nondestructive testing of concrete by the surface hardness method.

B-143 Rajagopalan, P. R., Jain, V. K., and Rai, M., "Ultrasonic Testing of Cement Mortar Subjected to Corrosive Chemicals," Indian Concrete Journal (Bombay), Vol 50, No. 7, July 1976, pp 213-216.

It is important to obtain a correct assessment of the extent of corrosion in cement mortar or concrete caused by chemicals, especially in aggressive environments such as those in fertilizer plants. For this purpose a nondestructive method of testing such as the ultrasonic pulse technique is to be preferred since it affords a quick, in situ method of checking a structure. The paper presents the results of a study in which the pulse velocity is correlated to the flexural strengths of mortar specimens made with ordinary

portland cement and portland blast furnace cement, and subjected to various corrosive chemical solutions with varying concentrations for different curing periods. Linear correlations were obtained in most of the cases. The results indicate that for more than 50 percent of the specimens, the strength could be predicted within a range of ± 10 percent, and for 90 percent of the cases within ± 20 percent.

B-144 Galler, S. "Corrosion Testing for Replacement of Deteriorated Concrete," Rural and Urban Roads, Vol 14, No. 8, Aug 1976, pp 21-22.

A municipal garage floor in New York City became a testing ground for the application of a new technology in using corrosion of reinforcing bars in concrete to determine the need for rehabilitation. The project, based on chloride level in the top reinforcing bar level, proved that such corrosion is an acceptable signal.

B-145 Hillerborg, A., Modeer, M. and Petersson, P. E., "Analysis of Crack Formation and Crack Growth in Concrete by Means of Fracture Mechanics and Finite Elements," Cement and Concrete Research, Vol 6, Nov 1976, pp 772-781.

A method is presented in which fracture mechanics are introduced into finite element analysis by means of a model where stresses are assumed to act across a crack as long as it is narrowly opened. This assumption may be regarded as a way of expressing the energy absorption in the energy balance approach, but it is also in agreement with results of tension tests. As a demonstration the method has been applied to the bending of an unreinforced beam which has led to an explanation of the difference between bending strength and tensile strength, and of the variation in bending strength with beam depth.

B-146 Malhotra, V. M., Testing Hardened Concrete: Nondestructive Methods, American Concrete Institute Monograph No. 9, Iowa State University Press, Detroit, 1976.

In the short span of four decades, nondestructive testing has achieved an important place in the quality control of hardened concrete and in the strength and durability evaluation of existing concrete structures. In certain instances, for example when investigating width and depth of cracking in concrete, nondestructive testing methods are the only ones that can provide reasonable answers.

This monograph is intended for the engineer engaged in the evaluation of hardened concrete. The various methods described satisfy two basic criteria: that the tests can be done on concrete structures in the field, and that the test equipment is portable and, with minor exceptions, based on the principles used in the testing of metals. Thus, many longstanding nondestructive tests such as Young's modulus of elasticity under limited stress are not covered because they fail to meet the basic criteria.

Fundamentals of the methods are given, testing apparatus explained, and limitations and usefulness noted. Mathematical treatment of the subject is kept to a minimum; necessary mathematical derivations are given in the appendixes.

Surface hardness and rebound tests, penetration and pull-out techniques, and dynamic or vibration tests are described in detail. A description of the combined methods approach, in which more than one nondestructive method is used to estimate strength of concrete, follows. Radioactive and nuclear methods are described. The magnetic, electrical, microwave absorption, and acoustic methods are of limited application and are only briefly discussed.

B-147 Weber, W. G., Grey, R. L, and Cady, P. D., "Rapid Measurement of Concrete Pavement Thickness and Reinforcement Location: Field Evaluation of Nondestructive Systems," National Concrete Highway Research Progress Report No. 168, 1976, Transportation Research Board, Washington, D. C.

This research project was initiated to develop alternatives to the current method of determining pavement thickness and reinforcement location by coring. Coring is time-consuming, costly, destructive, and of no use in quality control during construction. Furthermore, existing acceptance criteria, dictated by the limitations inherent in coring, are widely diverse and generally lack a precise statistical basis.

The major findings of this research are that:

1. An appropriate nondestructive method exists for determining the thickness of concrete pavement after the concrete has gained its initial set.

2. Another nondestructive method is available for determining the thickness of nonreinforced concrete pavement in either the plastic or the hardened state.

3. A stable, accurate, and dependable device exists for determining the location and depth of reinforcement steel in pavements.

4. The application of statistical quality control techniques has led to the development of an acceptance specification for pavement thickness that is equitable to both the producer and the owner. Additionally, this specification reduces the risk to the owner of accepting pavements grossly deficient in thickness without an excessive increase in sampling costs.

5. Three alternate methods of application of penalties were studied. It is believed that the choice of method utilized is a prerogative of the individual specifying agencies.

6. A simple attribute sampling plan for location of reinforcement position was also developed in this research.

SECTION C

MAINTENANCE AND REPAIR MATERIALS

1931

C-1 Jumper, C. H., "Tests of Integral and Surface Waterproofing for Concrete," Proceedings, American Concrete Institute, Vol 28, Dec 1931, pp 209-242.

This is a report of the study of integral and surface waterproofing materials for concrete. Fifty integral waterproofing materials were incorporated into a 1:3:6 concrete and subjected to a water pressure of 20 psi for one year and their permeability noted in comparison to plain concrete. Detailed discussion is given of the effect of each material on concrete.

Fifty surface waterproofing materials were applied to concrete cylinders and absorption figures obtained. Results were compared with ones obtained on uncoated concrete. A general resume is given.

1939

C-2 Blackmore, P. O., "Paint for Durability of Concrete Surfaces," Proceedings, American Concrete Institute, Vol 35, Jun 1939, pp 545-552.

Fourteen hundred concrete blocks were prepared under direction of Portland Cement Association and were painted and exposed at Cincinnati, Ohio, by the Ault & Wiborg Corp. Eleven types of concrete primers and five types of finishing coats were exposed in all possible combinations with each other. Two primers were outstanding. All finish coats behaved well over these two primers.

Colors used were red oxide, toluidine red, chrome green, ultramarine blue, iron blue, chrome yellow, chromium oxide, mapico yellow, and white. Results given in tabular form and discussed.

1942

C-3 ACI Committee 616, "The Nature of Portland Cement Paints and Proposed Recommended Practice for Their Application to Concrete Surfaces," Proceedings, American Concrete Institute, Vol 38, Jun 1942, pp 485-504.

The committee presents a detailed discussion of the characteristics and uses of paints whose base, and principal ingredient, is portland cement - the factors of composition and of technique in application for satisfactory service. The report is the foundation for a report to be presented later with a view to Institute adoption as a Standard Recommended Practice.

1944

C-4 Hornibrook, F. B., "The Effectiveness of Various Treatments and Coatings for Concrete in Reducing the Penetration of Kerosene," Proceedings, American Concrete Institute, Vol 41, Sep 1944, pp 13-20.

Measurements were made of the penetration of kerosene under a 12 ft pressure head into discs of concrete which had received various treatments or coatings. The tests were classified into seven groups as follows: (1) reference concrete, (2) integral admixtures, (3) sodium silicate and magnesium fluosilicate treatments, (4) plaster coats, plain and with admixtures, (5) magnesium oxychloride type coatings, (6) linseed oil and spar varnish coatings, and (7) synthetic plastic and latex coatings. Comparisons of the relative rates of penetration of kerosene into the specimens of each group are given, together with a discussion of various other properties of each group.

1946

C-5 Pocock, B. W., "Asphaltic Oil-Latex Joint-Sealing Compound," Proceedings, American Concrete Institute, Vol 42, Jun 1946, pp 565-580.

The development of asphaltic oil-latex compounds for use in sealing expansion joints in concrete pavements is discussed. Laboratory tests devised by the Michigan State Highway Department for evaluating these seals are described and results of field installations in Michigan are reported. Tentative Michigan specifications for this type of seal are given.

1947

C-6 Burnett, G. E. and Fowler, A. L., "Painting Exterior Concrete Surfaces with Special Reference to Pretreatment," Proceedings, American Concrete Institute, Vol 43, Jun 1947, pp 1077-1088.

Laboratory evidence is presented to demonstrate that pretreatment is invaluable if not essential to the successful use of oil-base paints on concrete surfaces. An effective pretreatment is described as consisting of a water solution of 2 percent zinc chloride - 3 percent phosphoric acid. With proper pretreatment, it is indicated that paint on concrete may last longer than paint on wood and that the customary extended aging period for concrete prior to painting may be omitted.

1949

C-7 Blanks, R. F. and Cordon, W. A., "Practices, Experiences, and Tests with Air-Entraining Agents in Making Durable Concrete," Proceedings, American Concrete Institute, Vol 45, Feb 1949, pp 469-488.

Discusses the advantages of air-entrainment with regard to durability, permeability, workability, reduction in alkali expansion, time saving, reduction in water and cement, temperature rise, strength, abrasion resistance, monolithic lightweight concrete, and mass concrete. U. S. Bureau of Reclamation experiences are discussed with regard to pumping, transportation and placing, grading of aggregates, and factors affecting the amount of air entrained. Air-entraining agents and air-entraining cements are discussed briefly. There is a brief section on the measurements of entrained air in concrete with a recommended procedure.

C-8 ACI Committee 616, "Recommended Practice for the Application of Portland Cement Paint to Concrete Surfaces (ACI 616-49)," Proceedings, American Concrete Institute, Vol 46, Sep 1949, pp 1-16.

This American Concrete Institute standard establishes recommended practices for appropriate usage, age of concrete, preparation of surface and the preparation application, and curing of portland cement paint. Three appendixes discuss composition, manufacture and storage, and general characteristics and factors affecting durability.

1950

C-9 Meissner, H. S., "Pozzolans Used in Mass Concrete," Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, p 16, 1950, American Society for Testing and Materials, Philadelphia, Pa.

Portland-pozzolan cement, or pozzolanic materials added to the concrete at the mixer, have been used on several mass concrete jobs in recent years. These cases are reviewed and discussed in connection with the characteristics of concrete made with such cementing materials and the advantages which they offer for mass construction. Material savings have been achieved by replacing a portion of the cement usually used with pozzolan, with resultant lower temperature rise and reduced cracking tendency without sacrificing ultimate strength in the concrete. It has also been shown that some pozzolans will aid in securing sound concrete with reactive aggregates. Comparison is made with two old dams, built with so-called "sand-cement," wherein the present day objectives in coping with cracking were achieved with concretes of low cement content supplemented with fine siliceous material.

1951

C-10 ACI Committee 212, "Admixtures in Concrete," Proceedings, American Concrete Institute, Journal, Vol 47, 1951, pp 25-52.

Five papers by members of American Concrete Institute Committee 212, Admixtures, are, because of their common general subject, presented together.

Various admixtures are discussed briefly as an introduction to more detailed treatment of air-entraining materials. The relative merits of admixtures and interground agents are considered. Optimum ranges of air content for different structural uses are given with particular reference to pavements.

The advantages and disadvantages of several types of admixtures used in the fabrication of various concrete products, such as building block, cast stone, pipe, cribbing and curbing are discussed. The admixtures considered are classified into the following groups: accelerators, air-entraining agents, gas-forming agents, water repellent agents, and workability agents.

The factors affecting bleeding characteristics and workability of fresh concrete are reviewed and the effect of admixtures on these properties is assessed.

Present knowledge of admixtures in counteracting alkali-aggregate reactions is reviewed. It is emphasized that further studies may revise thinking in this field.

The effectiveness of various concrete admixtures in inhibiting the capillary flow of water and the flow of water under pressure is considered. The types of admixtures included in the discussion are accelerators, soaps, butyl stearate, finely subdivided dry materials, mineral oil, workability agents, and a miscellaneous group of proprietary compounds.

C-11 Jackson, F. H. and Tyler, I. L., "Long-Time Study of Cement Performance in Concrete," Proceedings, American Concrete Institute, Journal, Vol 47, 1951, pp 773-796.

Test procedure, materials, mix proportions and construction procedures on the New York Test Road, a part of the "Long-Time Study of Cement Performance in Concrete," are described. All 27 of the Long-Time Study cements were used in conjunction with a nontest cement for adjusting equipment and mix proportions. Performance of the test sections is assessed with respect to durability of the concrete as a material, the only property directly studied in relation to the cement used.

Seven and one-half years after the test pavement was completed no one cement proved superior to the others tested. However, the effects of air entrainment in improving resistance of the pavement to scaling and weathering overshadowed all other variables. The use of abrasives with ice control chemicals caused scaling on nonair-entraining concrete. A 2- to 3-in. increase in slump of the test concrete has had no appreciable effect on the durability of the concrete.

<u>1956</u>

C-12 Moran, T. W., "Use of Gunite as Structural Material - Survey of Developments, 1930-1955," <u>Structural Engineer</u>, Vol 34, No. 2, Feb 1956, pp 37-55.

Main categories of work for which gunite is commonly used: case histories of reconditioning of reinforced concrete structures; strengthening of structures which have partially failed; durability of reinforced concrete structures and their repair. Bibliography.

<u>1957</u>

C-13 Mitchell, W. G., "Effect of a Waterproof Coating on Concrete Durability," <u>Proceedings, American Concrete Institute</u>, Vol 54, Jul 1957, pp 51-58.

Common denominator of all generally recognized types of concrete deterioration is water, either in liquid or crystalline form. Since concrete is characteristically a porous material, improvements in concrete itself are not likely to completely prevent ingress of potentially harmful water. Author believes waterproof coatings can speedily and economically improve concrete durability.

Freeze-thaw tests on beams coated with neoprene-latex showed significantly greater durability than that of uncoated specimens. Five-hr sand-blast test demonstrated improved abrasion resistance of neoprene-latex-coated specimens.

C-14 Lee, H. and Neville, K., <u>Epoxy Resins</u>, McGraw-Hill, 1957.

Industrial chemists, engineers, and designers are suddenly confronted with thermosetting materials with which they are completely unfamiliar. How do these new materials work, what are their strong points and their weak points and, most importantly, how can they be used intelligently for a specific application? These questions must be answered, if the advantageous properties of the epoxies are to be applied to the solution of today's complex technological problems.

This book is intended to provide theoretical and practical information on these new plastics and to answer many of the

questions which will occur to the user. The book discusses the technical background and general chemistry of the resins and indicates the specific formulations that can be developed and the application techniques that have proved successful.

The chemist will find a review of the synthesis, curing mechanisms, and curing agents involved in this new class of materials. The electronics engineer will find data on the potting of electrical components and their performance in high humidities; the power engineer will learn how epoxy resins have solved many of the application problems of electrical apparatus in corrosive environments; the paint and varnish formulator will find data on the formulation of both solvent and solvent-free coatings of unusually durable properties; the tool and die maker will find a detailed discussion of the casting resins which are creating a revolution in metalworking; the aircraft and missile engineer will find suggestions for lightweight sandwiches, high-compressive-strength laminates, high-temperature adhesives and chemically resistant sealants; the chemical engineer will find details on laminates for lightweight ducts and piping to handle corrosive fluids; and the automotive engineer will meet a versatile metal adhesive and body-patching compound.

1958

C-15 Lehmann, H. L. and Watson, C. M., "Thiokol Liquid Polymer/Epoxy Adhesive for Concrete," File No. 10-Th 1/57, Apr 1958, State of Louisiana Department of Highways, Testing and Research Section.

Laboratory and field investigations into the use of Thiokol Liquid Polymer/Epoxy Adhesive for concrete are described. The laboratory phase was designed around the repair of tensile test specimens and flexure test specimens. The tensile test specimens were used to substantiate the effect of the adhesive in the bond of old concrete to old concrete. The flexure test specimens were used to determine the effect of the bond of fresh concrete to old concrete.

The field phase of testing consisted of placing three concrete patches on a heavily traveled stretch of highway and observing the reactions at each line of demarcation between old and new concrete. The three test patches represent three different sets of circumstances for applications.

C-16 Callaway, W. R., "Epoxies Tested for Dam Conduits," Western Construction, Vol 33, No. 5, May 1958, pp 59-60.

Article includes a brief description of the tests conducted on epoxy resins to find their characteristics when used as a surfacing material for eroded concrete.

C-17 U. S. Army Engineer Ohio River Division Laboratories, CE, "Specifications for Epoxy Resin Grout for Installation of Dowels in Pavements," 10 Sep 1958.

Covers the proper quantities and mixing procedure for epoxy resins, design strengths, tests, procedure, and safety precautions for their use. A list of the principal manufacturers of epoxy resin bonding agents. A brief description is also given on the proper procedure to follow in the installation of dowels.

C-18 "Concrete Questions and Answers: Epoxy Resins as Adhesives," New Zealand Concrete Construction (Wellington), Vol 2, No. 8, Sep 1958.

Answers question, What are the benefits obtained by using epoxy resins as adhesives in concrete construction.

1959

C-19 Pepper, L., "Epoxy Resins for Use on Civil Works Projects; Summary of Data Available as of 1 March 1959," Technical Report No. 6-521, Report 1, Aug 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

An epoxy resin is a synthesized material, the molecules of which are characterized by ethoxyline ("epoxy") groups that serve as reaction sites for polymerization. Polymerization, initiated by the addition of a reagent known variously as a "curing agent," "hardener," "activator," or "catalyst," produces hardening. Dilutents or fillers or both are used to modify viscosity or affect other properties and reduce cost.

Epoxy-resin systems have been formulated, sold, and used for a wide variety of applications because of their strength, adhesion, stability at high temperatures, resistance to chemical attack, abrasion resistance, and electrical characteristics. This report reviews the available literature and manufacturers' publications to determine the potential uses of epoxy resins on Civil Works projects. These possible uses fall into three general categories: adhesives, fillers, and coatings. Specific applications that have proved successful include:

a. Bonding hardened concrete to hardened concrete.

b. Bonding freshly mixed concrete to hardened concrete.

c. Sealing cracks in concrete.

d. Filling voids, pop-outs, and spalls in concrete.

e. Refacing worn concrete or steel surfaces.

f. Coating concrete or other surfaces for resistance to chemical attack.

g. Protecting electrical components.

h. Bonding attached or embedded items such as dowels, reflector buttons, traffic bars, etc., to concrete.

The particular epoxy-resin system to be employed in a given application should be carefully selected to have the most appropriate characteristics as related to requirements of application, properties after curing, and lowest cost. In view of the many classes of use and circumstances of employment of epoxy-resin systems, it appears inescapable that there must be a large number of systems in order for each to approach the optimum for its particular application.

C-20 Gaul, R. W. and Apton, A. J., "Epoxy Adhesives in Concrete Construction," Civil Engineering (N. Y.), Nov 1959, pp 50-52.

Discussion is focused on epoxy adhesives which have been used in the repair of sidewalks, gutters, and chuck holes, the bonding of extruded dividers and traffic buttons, and the anchoring of runway dowels. The authors also give a brief evaluation on the strength of epoxy adhesives.

<u>1960</u>

C-21 Cardone, S. M., Brown, M. G., and Hill, A. A., "Latex-Modified Mortar in the Restoration of Bridge Structures," Highway Research Board Bulletin 260, Jan 1960.

A synthetic latex emulsion admixture was used with portland cement mortar in thin patching mixtures. Laboratory study showed improvement in shear bond strength, compressive strength, tensile strength, and a reduction of water-cement ratio as compared to regular mortar. The latex emulsion was added in amounts of 10 to 20 percent based on latex solids to cement weight. It was used in mortars having sand-cement ratios of 3:1 and 2:1 by weight.

Thin patching was applied to a bascule bridge deck in Cheboygan, Mich., during the fall of 1957. Evaluations of the thin-patched deck show that areas where the latex mortar was applied over a sound, wet substrate held up well through two winters. Bond failed during the first year in varying degrees in areas covered dry, with latex-cement slurry, or with a brush coat of the latex emulsion only.

The 1957 areas where bond failed were repaired in late 1958 by applying a different latex mortar over a cleaned substrate soaked with water prior to the patching application. After one winter these areas appear to be well bonded to the old surface. A few areas contain some fine shrinkage cracks but do not appear to be loosening.

The mortar mixes of 1957 contained a water-dispersed resin of a styrene-butadiene copolymer. A new latex emulsion of a Saran type was used in the 1958 patching mortars.

C-22 Howe, R. T., "Polyvinyl Acetate and Portland Cement Mortars," <u>Journal of the Construction Division, American Society of Civil Engineers</u>, Vol 86, No. CO1, Feb 1960, p 31.

Polyvinyl acetate, a synthetic resin widely used as a base for paints and adhesives, offers some promise as an admixture for portland cement mortars. This paper describes polyvinyl acetate, and outlines research on its possible use in a concrete floor surfacing material. Full-scale applications made several years ago are described and their present conditions evaluated.

C-23 Gaul, R. W., "Epoxy Adhesives - Uses of a Material New to Construction," Western Construction, Mar 1960, pp 63-74.

Typical applications of epoxy adhesives used in construction work are discussed with emphasis placed on the problems that occurred on the Skagit River bridge in Nehalem, Wash. where repairs to spalled concrete were accomplished through the use of epoxy adhesives.

The types of epoxies and their properties were discussed briefly as was the comparison of costs of labor and material in epoxy applications.

C-24 Proctor, T. G., "Structural Adhesives," New Zealand Engineering, Vol 15, No. 4, 15 Apr 1960, pp 113-121.

Structural adhesives are stable plastic compounds which can be safely stressed and have properties which enable them to be used for the adhesive bonding together of the materials commonly used in engineering. Since 1941 structural adhesives have been used in the aircraft industry and reliance is being placed on them to an increasing extent in the construction of modern high speed aeroplanes and missiles.

There are many complexities and the paper seeks to explain some of these to professional engineers. The first part of the paper covers fundamentals and much of what is said will serve as an introduction to the wider subjects of reinforced plastics, protective coatings, plastic tooling, shell moulding, as well as to various electrical uses.

The second section deals with technological aspects of achieving reliable adhesive bonds, and the final section introduces design. Emphasis throughout is on metal-to-metal bonding but it is expected that discussion may centre more on the bonding of wood and of concrete. Confidence has been established in New Zealand in adhesive bonding of quite large structures in wood. This confidence will lead to other structural uses but not perhaps for many years.

C-25 Simpson, W. C., Sommer, H. J., Griffin, R. L., and Miles, T. K., "Epoxy Asphalt Concrete for Airfield Pavements," Journal of the Air Transport Division, American Society of Civil Engineers, Vol 86, No. AT1, May 1960, p 57.

Studies of airfield-pavement problems which arise from the combined effects of heavy load, fuel spillage, and jet blast have led to the development of a new type of paving material called epoxy asphalt concrete (EAC). Conventional hot-mix asphalt plants and paving equipment are used in its production.

This material has Marshall stability values of 15,000 lb to 20,000 lb and is capable of withstanding tire pressures in excess of 1,000 psi. In repeated gyratory loading simulating B-52 traffic, EAC resists densification and retains its load-carrying ability. Good retention of strength and stability under severe conditions of solvent and fuel spillage has been established by experience in aircraft maintenance areas. In jet-blast tests with military planes, EAC performs well under normal pretakeoff conditions and with prolonged afterburner operation producing pavement temperatures of 800° F.

Investigation of its mechanical properties shows that EAC has a flexural strength or modulus of rupture exceeding that of portland cement concrete by a factor of 3 to 6. However, EAC has flexibility which allows it to be bent to the same extent as asphaltic concrete before fracture. The new paving material thus combines the strength of portland cement concrete with the flexibility of asphaltic concrete.

C-26 Tremper, B., "Repair of Damaged Concrete with Epoxy Resins," Proceedings, American Concrete Institute, Journal, Vol 57, No. 2, Aug 1960, pp 173-182.

The use of adhesives and binders containing epoxy resins by California Division of Highways in repairing concrete is described. Illustrations of their use in repair work are given. The discussion includes possible variations in formulation to secure wanted properties for specific uses, methods of application that are necessary to obtain strong and durable repairs, and a typical formulation for general use.

C-27 "Neoprene-modified Asphalt for Turnpike Maintenance," Public Works, New York, Vol 91, No. 5, 1960, pp 176-177.

Cut-back bitumen grade RC-2 or RC-3 is being mixed with 1-1/2 percent by weight of neoprene for surface dressing on shoulders of the New Jersey Turnpike. The addition of neoprene is said to increase workability, retention of aggregate

and elasticity. It is heated to between 150° and 200° F and applied by a standard pressure distributor at the rate of 3 gal/sq yd on top of a 3-in. course of penetration macadam; 3/8-in. aggregate is then applied at 25 lb/sq yd. An emulsion of bitumen and 3 percent by weight of neoprene is used for filling cracks; it is said to cure faster and have greater bonding effect than other materials. It is also used for joint filling between concrete slabs.

1961

C-28 England, O. L., Pepper, L., Kennedy, T. B., "Sulfate-Resistant Concrete; Literature Review," Technical Report 6-569, Report 1 May 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Limited review of technical literature to determine present state of knowledge concerning (a) nature and mechanism of sulfate attack on concrete, (b) methods of minimizing or preventing attack, and (c) methods of guarding or restoring structures affected by sulfate attack.

C-29 "Epoxy Glues Pontoons Together to Make Floating Bridge," Construction Methods, Vol 43, No. 8, pp 42-95, Aug 1961.

Epoxy resin is helping to join 23 big concrete pontoons into a floating bridge across the Hood Canal. The units originally were to be coupled together by bolts and a cement grout. But after 10 of the pontoons had been assembled, the joints failed during a severe storm and had to be redesigned.

The new joint design heavies up the bolts and replaces the cement grout with a fast-setting epoxy polysulphide cured with amine. Mixed with sand and poured into 1-1/2-in. gaps between the ends of adjacent pontoons, the resin cures into a substance with an estimated ultimate compressive strength of 10,000 psi. And it can take a certain amount of flexing during its cure without destroying its bond to the concrete.

Typical pontoon is 360 ft long, 50 ft wide, and 14 ft deep. Before the units can be bonded with the epoxy grout, their 14- by 50-ft end faces must be prepared in the dry.

In preparation for pouring the epoxy bond, the pontoon ends are heated to speed the curing reaction. A 75-kw diesel generator supplies 440-v current to 48 heating elements, each

14 ft long. These hang in the 1-1/2-in. gap, suspended from spikes across it. Boards cover the gap between elements to minimize heat loss.

Four to six thermocouples in the gap tell when the required 125° F temperature is reached, usually in 6 to 12 hours. The thermocouples also keep track of temperature during pouring and curing of the bonding material.

This grout consists of sand and two components of Concresive No. 17.

The bonding operation takes about three hours. First, heating elements are removed from the gap between pontoons and replaced with five metal-lined wooden funnels. Near each funnel is a mixing station where the grout is prepared. The drill is mounted on a couterweighted timber lever arm for easy insertion or removal of the paddle from a 5-gal mixing bucket.

C-30 James, J. G., "The Use of Epoxy Resins in Road and Bridge Surfacing," Resin Review, Vol 1, No. 3, 1961, pp 6-8.

Some uses of epoxy resins in road engineering are listed, and an account is given of laboratory and full-scale experiments carried out by the Road Research Laboratory, Harmondsworth, between 1958 and 1960 in cooperation with manufacturers. These include surfacings for timber and steel bridge decks, white line markings on concrete, surface dressing of a slippery concrete roundabout, and repair of spalled concrete surfaces and joints.

C-31 Tyler. O. Z. and Drake, R. S., "Superior Strength Properties with Polymer Modified Portland Cements," Adhesive Age, Vol 4, No. 9, 1961, pp -39.

The tensile strengths of vinyl-modified cements are higher than the unmodified type cured under ideal conditions; that is, under water, but dry-cured tensile strengths are generally lower than those modified with commercially accepted latices; use of a vinyl copolymer with polyvinyl acetate latex improved dry-cured strengths without change in wet-cured strength. Butadiene-styrene latex additions are also considered. The general characteristics of these systems are considered but

stress is laid on the increased cost, which may be appreciable since 15-20 percent of polymer is required to improve upon the natural properties of cement. Several formulations are given and various special applications are indicated.

1962

C-32 Smith, P., "Observations on Protective Surface Coatings for Exposed or Asphalt-Surfaced Concrete," Bulletin 323, pp 72-95, Jan 1962, National Research Council, Highway Research Board.

If a suitable surface coating could be found that would keep concrete dry and prevent the entry of salt solution, a significant reduction in scaling and spalling, together with a general improvement in durability might be expected. The observations made are based on the inspection of treated structures and pavements, controlled field trials, and laboratory evaluations which may be indicative of the effects of a wide range of surface coatings in improving (or otherwise) the freeze-thaw durability and scaling resistance of concrete.

Results appear to show that faith in conventional surface coatings such as linseed oil or bituminous products (other than normal asphalt surfacings) is more justified than hope in more exotic substances. With many protective coatings the importance of such side issues as the difficulty of attaining adequate bond with an overlying asphalt surface or the adverse effects of sealing all the exposed surfaces of a concrete section has become apparent. Pending completion of the investigation an interim conclusion is that, although surface coatings are not in themselves the answer to making concrete durable, a suitable one, correctly and selectively applied, may offer a worthwhile additional line of defense to reinforce air entraining in new construction or retard further deterioration in older structures or pavements.

C-33 Pimbley, C. E., "Epoxy Coating Guards Powerful Nuclear Reactor," Research and Development, Vol 13, No. 4, Apr 1962, pp 54-58.

Brief summary of the procedures followed in applying epoxy coating to nuclear reactor vessel.

AD-A062 694 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 5/2
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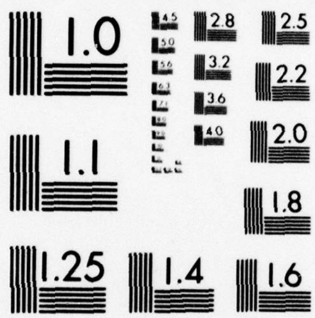

MICROCOPY RESOLUTION TEST CHART
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C-34 American Concrete Institute Committee 403, "Guide for Use of Epoxy Compounds with Concrete," Proceedings, American Concrete Institute, Vol 59, No. 9, Sep 1962, pp 1121-1142.

Describes proper procedures for the use of epoxy resin compounds for skid-resistant overlays, waterproofing, patching, crack and joint sealing, bonding new concrete or hardened concrete to old concrete, grouting, coatings to prevent chemical attack and other uses. Methods of surface preparation of both concrete and steel, removing contamination prior to applying epoxy compounds, and for applying the epoxy resin compound are described. A test for appraising the soundness of the concrete surface and adhesion to it is suggested. Since epoxy compounds are often toxic, safe handling practice is extensively discussed.

C-35 "Linseed Oil Emulsion Prevents Salt Damage to Concrete Paving," Iowa Municipalities, Vol 17, No. 9, Nov 1962, p 19.

A timely hint for municipal street departments may be found in the practice of the Iowa State Highway Commission of sealing concrete pavements poured late in the year with linseed oil emulsion to prevent salt damage. This protection is considered desirable for even air-entrained concrete that will not have time to cure fully before freezing weather comes on.

The state started using the linseed oil preparation in 1953. The emulsion consists of kerosene, soap powder, trisodium phosphate, and water, and is spread with a bituminous distributor. When the coating has dried, a residue is retained in the pores of the concrete which prevents salt brine from penetrating the pavement.

C-36 Blanchard, R. S. and Britton, H. B., "An Application of Glass Fiber Reinforced Resin Wearing Surface," Highway Research Abstracts, Vol 32, No. 11, Dec 1962.

This paper deals with the concept and application of a new type of wearing surface.

This material and its method of application were developed by members of the Northern Fibre-Deck Association in conjunction with the New York State Department of Public Works. This wearing surface was first used in New York State under a contract in which the Bureau of Public Roads participated.

The three-part presentation relates information regarding the concept and development of the wearing surface, shows the actual installation of a glass fiber reinforced resin wearing surface, and gives data regarding weight and cost of this type application.

C-37 Base, G. D., "Shear Tests on Very Thin Epoxy Resin Joints Between Precast Concrete Units," Technical Report No. TRA/366, 1962, Cement and Concrete Association.

Thirty-six short concrete beams, each consisting of three matched concrete blocks glued together with thin films of an epoxy resin, were tested to determine whether the joints had adequate shear strength.

The main variables were the method of preparing the contact surfaces, the method of applying the resin and the pressure (prestress) applied through the joints during setting and testing.

A simple method of applying pure shear to the joints was developed during the tests.

It is doubtful whether any failures were initiated by the actual resin although, with no prestress, average shear stresses up to 680 lb/in^2 were applied. Indeed, the fact that an increase in the strength of the concrete was followed by a significant rise in ultimate shear strength would point to a concrete failure in the joint. The use of mould oil in the preparation of the contact surfaces resulted in failures in the concrete into which the oil had penetrated. Some bending tests on the joints showed that the bending strength of the joint was greater than that of the adjacent concrete.

C-38 Welch, G. B., Carmichael, A. J., and Hattersley, D. E., "Epoxy Resin Concrete," Civil Engineering and Public Works Review, Vol 57, 1962, pp 759-761.

The paper presents details of experimental investigations into new concrete materials in which an epoxy resin replaces the usual cement-water paste as the binding constituent.

The epoxy concretes have generally very high strength characteristics, with particularly high tensile and bond strengths. Figures for elastic modulus, Poisson's ratio, curing shrinkage, thermal movement, etc., are also given for typical epoxy concrete mixes, together with details of different aggregate gradings and resin formulations examined.

The important influence of varying the composition of the epoxy binder, by including a flexibilising modifier to increase flexibility is demonstrated by the results, and a satisfactory compromise which gives intermediate properties is indicated.

<u>1963</u>

C-39 L'Hermite, R. and Jejcic, D. "Resin Concrete," <u>RILEM Bulletin No. 18</u>, Mar 1963, pp 87-92.

While it is true that numerous laboratories have examined the problems raised by these new materials, resin concretes and their applications in building, there is scarcely a field in which the research worker and the practical man are so little informed as to the work of their colleagues. And yet, the relative novelty of this field should be an additional reason for intensifying collaboration among laboratories and should, for logical reasons, promote exchange of information.

One of the objectives of this symposium by correspondence was precisely to provide a field of comparison for the various experiences acquired by the development of methods for testing resin concretes. Some of these tests must have required specially designed apparatus, or at least a modification of standard apparatus; here also information is lacking. And it would certainly be valuable to be able to compare points of view on the interpretation of results. This symposium should also permit an exchange of views on the use of resin concretes in building and the prospects that can already be discerned as to its future applications. Finally, the participants were requested to present any suggestions they might have as to tests to be undertaken with a view to determining all useful characteristics of resin concretes.

C-40 "Four-Hour Concrete Patching with Low-Shrinkage Admixture," Roads and Streets, Vol 106, Jun 1963, pp 96-97 and 100-101.

The use of fast-setting portland cement concrete to resurface broken sections of concrete pavements is compared to the use of epoxies. The advantages favor the concrete. A quick-setting admixture in the portland cement concrete allows the mix to achieve 20-day strengths in 24 hours. A quick-set marketed under the trade name of Liquid Sika-Set was used. This additive can be used with conventional cement as well as high-early cement.

C-41 Dolch, L. W., "Protective Coatings for Concrete," Technical Report No. 2-29, Sep 1963, Ohio River Division Laboratories, U. S. Army Engineer Division, CE, Ohio River, Cincinnati, Ohio.

A review of some aspects of protective coatings for concrete comprising a selected bibliography with brief annotations and a summary of the state-of-the-art as revealed by the references cited. The report is concerned chiefly with coatings that have been used to protect concrete from water ingress. Basic principles of waterproofing and dampproofing are discussed. Protective coatings are classified into seven categories, i.e., cement base paints, solvent-thinned paints, emulsion paints, bituminous coatings, silicones, epoxy and related coatings, miscellaneous coatings, and each class is discussed separately.

C-42 American Concrete Institute Committee 212, "Admixtures for Concrete," Proceedings, American Concrete Institute, Journal, Vol 60, Nov 1963, pp 1481-1524.

This third report of American Concrete Institute Committee 212, Admixtures for Concrete, updates the previous reports of 1944 and 1954. In this report admixtures are classified in 15 groups according to type of materials constituting the admixtures, or to the characteristic effects of their use. Where an admixture possesses properties identifiable with more than one group, it is discussed with the group that describes its most important effect on concrete. Types of admixtures discussed are: (1) accelerating; (2) water-reducing

and set-controlling; (3) grouting; (4) air-entraining; (5) air-detraining; (6) gas-forming; (7) expansion-producing; (8) finely divided mineral; (9) damp-proofing and permeability-reducing; (10) bonding; (11) alkali-aggregate-expansion-reducing; (12) corrosion-inhibiting; (13) fungicidal, germicidal, and insecticidal; (14) flocculating; and (15) coloring. An extensive list of references is included.

C-43 Miklofsky, H. A., Gonsior, M. J., and Santini, J. J., "Further Studies of Epoxy Bonding Compounds," Physical Research Project No. 13, Dec 1963, Rensselaer Polytechnic Institute.

This report is a study in detail of an epoxy formulation called Formulation G which is suitable for application in the field of heavy construction. One type of such construction has been simulated by means of composite beam tests; however, the investigators feel that the most important part of the study has been the development of basic information concerning the physical properties of a single epoxy formulation, both as a plastic and as an adhesive, in several ranges of conditioning temperatures and curing times. An interim report published in October, 1962, gave information on Formulation G for specimen ages of 4 through 22 days in particular, and also gave some information for specimen ages of several months. This final report has concentrated on filling in more fully the basic information during the early ages of the specimens, and also presents information of long time studies involving the aging and creep characteristics of the material.

C-44 Hussell, "Freeze-Thaw and Scaling Tests on Silicone-Treated Concrete," Highway Research Record No. 18, pp 12-32, 1963, Highway Research Board.

Laboratory tests of freeze-thaw durability and scaling resistance of concretes treated with silicone water repellents indicated that the silicone gave no appreciable benefit to air-entrained concrete; a slight improvement was noted in the durability and scaling resistance of silicone-treated nonair-entrained concrete.

C-45 Johnson, R. P., "Glued Joints for Structural Concrete," The Structural Engineer, Vol 41, No. 10, 1963.

A review of existing literature on epoxy concrete (in which glue is used in place of cement) and on the use of epoxy and polyester resins for joints in concrete shows that joints stronger than the concrete can be made but that poor surface preparation leads to a serious loss of strength. There is little information on the creep of joints under shear stress.

The first series of tests was carried out on glued lap joints between prestressed or reinforced concrete members. Twelve joints were tested in pure shear and two in torsion. The method of loading ensured that there was no resultant force normal to the plane of the joint. The results show the important effect of surface preparation on the creep under constant shear force and on the ultimate strength of the joints. Tests on cylinders of epoxy resin glue are also reported.

Calculations based on the theory of elasticity suggest that longitudinal prestress should increase the strength of a lap joint; the tests show that the increase is too small to justify the use of prestress for this purpose. At failure the mean shear stress in the joints was roughly equal to the split-tensile strength of the concrete.

In the second series of tests the variable was the force normal to the plane of the joint. Creep of the glue led to failure of some joints under a sustained load of less than half the short-term strength.

C-46 Klieger, P. and Perenchio, W., "Silicone Influence on Concrete Resistance to Freeze-Thaw and De-Icer Damage," Highway Research Record No. 18, pp 33-47, 1963, Highway Research Board; Also reprinted as Research Department Bulletin 169, Portland Cement Association.

This paper presents the results of a comprehensive laboratory study on the effect of various silicones, used as surface treatment or as integral admixture, on the resistance of concrete to freezing and thawing and de-icer scaling. Various types of nonair-entrained and air concretes were used.

Results indicate that the surface silicone treatments resulted in lower resistance to freezing and thawing and to

de-icer scaling, particularly for the nonair-entrained concretes and the concretes with an inadequate amount of intentionally entrained air. Although applications of silicone surface treatments reduced the initial rate of absorption of water, on continued immersion for periods ranging from 7 to 14 days the total absorptions for treated and untreated concretes were essentially identical.

These studies indicate that the use of silicones for treatment of horizontal concrete surfaces such as pavement slabs or bridge decks may be detrimental rather than beneficial with regard to resistance to freezing and thawing and de-icer scaling. The most effective means for insuring such durability was to provide an adequate amount and character of entrained air in a concrete of relatively low water-cement ratio.

Silicone as an integral admixture appeared of little benefit in the performance of the nonair-entrained concretes. Vertical surfaces of air-entrained concretes were treated with silicones and then subjected to freezing in air and thawing in air with intermittent water spraying. These showed a reduced tendency to wet; however, both treated and untreated vertical surfaces showed excellent resistance to this type of exposure.

1964

C-47 "Expanding Cement Prevents Roof Cracks," Engineering News-Record, 16 Jan 1964, p 32.

This paper describes a new shrinkage-compensated cement. Shrinkage-compensated cement is a formulation of new expanding cement and portland cement. The mixture produces concrete that expands slightly, in a predetermined amount, as it cures, thus counteracting the normal shrinkage that portland-cement concrete undergoes.

The last portion of the article states places that this mixture is available.

C-48 Alumbaugh, R. L., "Epoxy Sealers and Bonding Agents for Concrete," Technical Report No. R 271, Mar 1964, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Preservation and maintenance of concrete and concrete-masonry structures exposed to a marine environment is often a serious problem within the Naval Shore Establishment. The problem exists primarily because suitable preservative materials have not been available in the past to prevent deterioration of concrete structures or to properly maintain these structures as they have deteriorated.

In testing epoxy resin formulations for use as sealer coatings and bonding agents (adhesives, caulking compounds, and crack fillers) for concrete and concrete-masonry materials, the work was divided into two phases. The first was concerned with the use of epoxies as sealer or dampproofing coatings while the second phase was concerned with their use as bonding agents.

C-49 Britton, H. B., "Epoxy Repairs for Viaducts," Rural and Urban Roads, Mar 1964, pp 32, 33, 37, and 83.

The Major Deegan Expressway is a dual six lane highway that carries up to 48,000 vehicles a day and has been clocked at peak periods carrying 4600 vehicles per hr. The ratio of truck to automobile vehicle traffic is exceptionally high and all traffic moves at relatively high speed. The expressway includes two viaduct structures, one of which is 4350 ft and the other 2800 ft long. When the roadway of these structures began to ravel under traffic load the State of New York Department of Public Works turned to epoxy resin seals to rehabilitate them. The operation under traffic is described in considerable detail. It included the removal of the existing portland cement concrete wearing course, the application of an epoxy protective membrane, and the placing of a 4 in. hot mix stone-filled sheet asphalt wearing course.

Preparations for the epoxy protective membrane include, after removal of unsound material and patching of the structural deck, etching with 15 percent muriatic acid solution, clean water rinse, picking up rinse water with pumps, sand blasting, sweeping, and vacuum cleaning.

C-50 Grieb, W. E. and Appleton, R., "Effect of Linseed Oil Coatings on Resistance of Concrete to Scaling," Public Roads, Vol 33, No. 1, Apr 1964.

This article reports the results of a study of the use of linseed oil surface coatings to prevent scaling caused by the

use of deicing chemicals. These tests were made because of the wide variation in the state specifications concerning the pavements against scaling caused by the use of deicing chemi-Bureau of Materials and Procedures for protecting concrete pavements against scaling caused by the use of deicing chemicals. These tests are being continued. In this investigation four different linseed oil surface coatings were used on air-entrained and nonair-entrained concrete with high and low slumps.

The data presented show that for nonair-entrained concrete, all of the linseed oil coatings were of some benefit in protecting the concrete surfaces from scaling. However, for the air-entrained concrete, only two of the surface coatings tested were beneficial.

C-51 "Dough Mixer Batches Up Epoxy Armor," Construction Methods, Vol 48, No. 8, Aug 1964, pp 85-87.

Epoxy armor is being tested as a possible wear surface inside two concrete intake passages at Milford Dam replacing the stainless steel normally used. The plastic armor was applied in three forms: the epoxy itself, an epoxy mortar, and an epoxy grout. One section was left exposed as a control to compare the performance of the plastic.

C-52 Oepkes, J. "Properties of Floor Surface Coatings Based on Filled Epoxy Resins," RILEM Symposium, Liege, 1964.

A short summary of the three types of floor surface coatings is given along with the properties of an optimum formulation. The author points out the fact that because of the high flexural strength and adhesion properties, filled epoxy resins can also be used on relatively flexible substances such as wood and steel.

C-53 Wilson, D. S. and James, J. G., "The Use of Epoxy and Other Resins in Road and Bridge Surfacings," RILEM Symposium, Liege, 1964.

Over the last three years various resinous materials have been investigated for their use as light-weight impermeable

and durable wearing surfaces for roads and bridges. These resins provide the binder for various aggregates to give different forms of surfacing from surface-dressing films to premixed mortars that are trowelled to a thickness of 3/8 in. Such surfacings have been applied to asphalt roads, and to bridge decks of concrete, steel, aluminum, and wood. The life of the resinous surfacing has not yet been evaluated, but after three years the trowelling mortars appear in good condition on a road bridge carrying heavy traffic.

The work carried out so far indicates that the mechanical and physical properties of the resins that were developed for flooring purposes have to be modified to make them suitable for roads and bridge decks. Moreover, some form of modification to the design of a metal bridge deck so as to avoid sharp curvature of the deck plate under load may help in arriving at a satisfactory type of surfacing.

A programme of laboratory tests is being carried out on the resin binders and on the surfacing mixtures to measure their tensile strength, elastic modulus, coefficient of thermal expansion, impact strength, adhesion, flexibility and the fatigue factor under repeated flexure.

<u>1965</u>

C-54 Thompson, P., "What We Learned About Epoxy Treatment for Bridge Decks," <u>Public Works</u>, Vol 96, No. 2, Feb 1965, pp 118-120.

Method of application of facial treatment consisting of 2.5 lb of epoxy covered with 22 lb of 30-mesh garnet/sq yd to stop deterioration of 28-year-old bridge deck is described; epoxy at 3 lb/sq yd was applied and spread with notched squeegee to get uniform coverage.

C-55 Levitt, M., "Fire-Resistance of Resin-Jointed Concrete," <u>Proceedings, Plastics Institute-Plastics in Building Structures</u>, Paper 12, 14-16 Jun 1965, pp 77-81 and 103-107.

Isothermal tests at ambient oven temperatures of 200°, 300°, and 400° C were conducted with resin-mortar-jointed high-strength firebricks to study effects of heat upon resin, ignoring substrate behavior; using two types each of resin, catalyst, and filler, only significant variable was type of resin, with polyesters showing superiority to epoxies; fire tests on resin-repaired concrete also showed that epoxy resin system degraded more rapidly than polyester resin repairs.

C-56 Lange, H. F., "Epoxy Paving Cement Fights Bridge Deck Wear," Public Works, Vol 96, Jun 1965, pp 113-115.

Epoxy/coat tar resinous pavement cement to seal against salt solutions and moisture on 6-lane bridge over Mystic River. This bridge averaged 65,000 vehicles per day and the pounding created by peak vehicular loading and the chemical attack and weathering caused severe erosion. Considered as suitable materials for resurfacing were: asphaltic concrete, silica sand-asphalt and the material used, epoxy/coat tar resinous paving cement. The trade name is Guardkote, developed by Shell.

C-57 U. S. Army Engineer District, CE, Kansas City, "Epoxy Resin Coatings," Interim Report No. 1, Jun 1965, Laboratory Investigation and Field Application, Milford Dam and Reservoir, Republican River, Kansas.

This report shows the results of Epoxy-resin, Epoxy-resin mortar and Epoxy-resin grout substitutions for 3/4-in. steel plating used for corrosion and cavitation resistance. The resin consists of the base epoxy-resin mixed with a thixatropic mixing agent and asbestoes binder. The report shows its mixability, trowelability, durability to freezing and thawing and its resistance to abrasion. Includes comments about its properties and recommended practices.

C-58 Scholer, C. H. and Best, C. H., "Concrete Curing and Surface Protection with Linseed Oil," Kansas State University Bulletin, Special Report No. 60, Jul 1965.

Tests of the durability of reinforced, air-entrained concrete samples under conditions of freezing and thawing in an aqueous solution of 2 percent sodium chloride are described. Conditions of test include 3000-psi and 5000-psi concretes containing crushed dense sandstone coarse aggregate and 3000-psi concrete containing crushed porous limestone coarse aggregate.

Deterioration of all three concretes protected with one or more coatings of linseed oil in mineral spirits is compared with the same concretes without protection. Deterioration of the 3000-psi concrete containing crushed porous limestone coarse aggregate and protected with a coating of water-emulsifiable linseed oil applied as a curing compound is compared with the same concrete without protection.

It is apparent from the photographic record that both types of protection are effective in impeding the progress of freeze-thaw damage and that periodic retreatment with linseed oil further arrests the damage under the conditions of test noted.

C-59 Walsh, R. J., "Linseed-Oil Protection for New York State Thruway Bridges," Civil Engineering (N. Y.), Vol 35, No. 7, Jul 1965, pp 39-41.

After experimentation, New York State Thruway Authority is using mixture of linseed oil and mineral spirits, applied by spraying, to bridge sidewalks, curbs, and railings of concrete for protection against chlorides: visual inspection indicates that three-coat protection of 40% linseed oil and 60% petroleum mineral spirits is effective; maintenance program provides for sealing all new concrete 28 days after placement, then adding another coat the same year and an additional coat in second and third years, with renewal coat every 5 yr thereafter.

C-60 Booth, R. L., "Linseed Oil Cuts Spalling Damage," American City, Vol 80, No. 9, Sep 1965, pp 96-97.

Method adapted by Connecticut State Highway Dept of treating all of exposed paved surfaces and curbing with two-phase application of linseed oil-mineral spirits mixture to protect bridge and elevated highway structures from spalling damage is described; to facilitate program, standard dump body truck with spray bar rig was adapted; bypass gasoline-driven pump recirculates material in 55-gal drums to provide approximately 100 lb of pressure at nozzle.

C-61 Jejcic, D., "General Report," RILEM Bulletin No. 28, (Reunion Internationale des Laboratoires d'essais et de Recherches sur les Materiaux et les Constructions), Sep 1965, pp 7-13.

A general discussion is given on the studies involved in the symposium on resin concretes. The author discusses briefly the different types of binders used and the advantages and disadvantages of their properties. The opinions of various

authors contributing to the symposium are given as to the performance of resins used for protection, insulation, and the gluing of concrete surfaces together.

C-62 Kreijger, P. C., "Concrete Connected to Concrete by Means of Resins," RILEM Bulletin No. 28, (Reunion Internationale des Laboratories d'essais et de Recherches sur les Materiaux et les Constructions) Sep 1965, pp 45-58.

The difference in behavior of a connection of hardened concrete to hardened concrete by means of resins is described for an epoxy-resin and a polyester-resin, both Dutch trademarks. The epoxy-resin gives a reliable connection, the polyester-resin does not do this.

It was not possible to find the cause(s) for the last-mentioned fact, despite investigations about the quality of the glue, the condition of the concrete to be glued, the technique of the glueing and the behaviour of the glued connection under different curing conditions.

C-63 Okada, K., "Resins for Concrete in Japan," RILEM Bulletin No. 28 (Reunion Internationale des Laboratoires d'essais et de Recherches sur les Materiaux et les Constructions), Sep 1965, pp 73-79.

This paper describes briefly the present status of studies on various resins used in the concrete works of both fields of Civil Engineering and Structural Engineering in Japan. In Japan, various resins, especially epoxy resins and some polymers are used on a trial basis as admixtures, bonding of surface coating materials just under way, though many researches have been made on the resins for concrete, and earnest efforts are devoted also by the manufacturers to produce them at lower cost and even to discover more useful ones in cooperation with the concrete researchers and engineers.

The Society of Materials Science, Japan (JSMS), has the Technical Committee on Resins for Concrete Works, by which the meeting is held regularly every two months discussing the results of studies done by various researchers including the concrete and the chemical engineers for better utilization of the resins.

C-64 Warren, C. K., "Resin Bonded Concrete," (with comments by G. Periale, M. W. Franke, and R. Bares), RILEM Bulletin No. 28 (Reunion Internationale des Laboratoires d'essais et de Recherches sur les Materiaux et les Constructions) Sep 1965, pp 109-119.

There are three main variables involved in the production of resin-bonded concrete:

1) The resin system.

2) The selection of aggregates.

3) The technique employed.

It was decided at the beginning of this programme that the best approach would be to select a technique and suitable resin system which promised the highest strengths at low resin concentrations. Then, after a comparatively brief examination of the variables within the technique, to obtain the optimum conditions, the main course of the investigation would be directed towards determining the effect of variations in the aggregate gradings. It was envisaged that at a later stage, using the experience gained, it would be possible to examine different resin systems and techniques in a more systematic manner than would have been possible initially.

C-65 Chaiken, B., "Abrasion Resistance of Bridge Paints for Use in Alaska Field and Laboratory Tests Evaluated," Public Roads, Vol 33, No. 10, Oct 1965, pp 201-213.

Findings from study of resistance of paint systems to abrasion in Alaska Copper River Delta area are reported: tests were made to determine most suitable paint system for this area where it must resist abrasion from extremely large amounts of aeolian sand, silt, and ice crystals carried by winds having high velocities of 90 mph; superiority of catalyzed polysulfide paint system was demonstrated; other paint systems evaluated were coal tar, drying oil, alkyd, vinyl, epoxy ester, zinc-rich inorganic, neoprene, and conventional red lead primer and aluminum varnish system.

C-66 "Epoxies That Cure at '20 Below'," Roads and Streets, Vol 108, No. 11, Nov 1965, p 99.

A breakthrough in epoxy resin research has brought a series of epoxies that cure at temperatures as low as -20° F. They also cure far more rapidly and have a reasonably long pot life.

The epoxies are reported to be the first to cure at below-freezing temperatures (lowest previous, 35°F).

The new series of adhesives thus has a dual use. They bond at low temperatures, previously considered impossible, and because of their extremely rapid cure times at normal ambient temperatures they can be used in applications where fast bonding is either highly desirable or an absolute necessity.

C-67 Snyder, M. J., "Protective Coating to Prevent Deterioration of Concrete by De-icing Chemicals," National Cooperative Highway Research Program Report 16, 1965, Highway Research Board.

The deterioration of concrete bridge decks and structures resulting from scaling caused by the increasing use of de-icing chemicals has become an increasingly serious problem in the northern states. Although the entrainment of air in the concrete and adequate curing before exposure to severe deteriorating conditions provide a reasonable degree of resistance to de-icing chemicals, for various reasons these desirable conditions are not always achieved in practice. Thus, a more positive protection is desirable. Previous studies and field trials have indicated that a number of protective coatings afford some degree of protection against de-icing salt attack on concrete structures that have not been adequately protected by air entrainment. This report presents the results of a laboratory investigation to determine which of the potential protective coatings are most effective and economical and to develop new coatings that would provide maximum protection and economy.

Observations of the rate of scaling of a standard non-air-entrained concrete specimen subjected to repeated freezing and thawing while covered with a salt solution was the principle means used to evaluate the various coatings. The degree of scaling was visually rated on a 1 to 5 scale by comparison with a standard set of specimens that exhibited varying degrees of scaling.

A total of 110 coatings was evaluated in the program, including linseed oil solutions and emulsions, solutions of other vegetable oils, epoxy and modified epoxy coatings, a

number of other synthetic resin coatings, rubber coatings, tars, asphalt, waxes, oils, and various inorganic coatings and treatments. Although the coatings represented an extremely diverse assortment of materials, good protection of nonair-entrained concrete was obtained only with a few. These few included coatings based on linseed oil or other vegetable oils and a sand-filled coal tar epoxy coating. The majority of the organic coatings failed rapidly by flaking or peeling from the surface of the concrete. Most of the inorganic coatings and some of the organic coatings were appreciably permeable to the salt solution and afforded protection only for a short time. Considering both economy and performance, the best results by far were obtained with vegetable oils and, particularly, linseed oil solutions.

In view of the excellent results with linseed oil solutions, attention was given to determining the optimum composition, application conditions, and application rates for linseed oil solutions. The results showed that the 50:50 mixture of boiled linseed oil and mineral spirits now used by a number of state highway departments was about the optimum composition and that the normally used application rates were satisfactory. Kerosene, which has a higher flash point than mineral spirits, could be substituted for the mineral spirits without affecting the performance. In trials on partially-scaled concrete it was found that removal of loose scale and washing to remove absorbed salt solution was advisable.

Experimental studies of the salt-scaling process showed it to be intimately associated with the lowering of the freezing point of water by de-icing chemicals. The effect is physical rather than chemical and arises from the development in the concrete of a depthwise gradient in the concentration of the de-icing compound. The stresses that cause the concrete surface to scale probably are a combination of thermal and hydraulic stresses.

1966

C-68 American Concrete Institute Committee 506, "Recommended Practice for Shotcreting (American Concrete Institute 506-66)," Proceedings, American Concrete Institute, Journal, Vol 63, No. 2, Feb 1966.

Recommendations are given on the applicability of shotcrete to different types of construction, material requirements, and application procedures. Equipment requirements are given for both the dry mix and wet mix processes. The testing of shotcrete is covered in some detail.

The necessity for a well-qualified application crew is stressed.

C-69 "Protecting Concrete Surfaces," Concrete Construction, Vol 11, No. 2, Feb 1966.

This paper deals with three types of protective coating. It also discusses methods used to protect and prepare the substrate. And the article gives descriptions and methods of application of the three coatings.

The first type - Cement Based Coatings - usually consist of a mixture of white portland cement, silica sand, pigment when required, accelerators and water repellents. Since the coating forms a film which is continuous it can be put in the category of dampproofing only.

The second type - Silicone Treatments - is not a vapor barrier and therefore allows the substrate to breathe. This treatment is usually good for four or five years. After this period of time another silicone application should be made. The material is very inexpensive and generally supplies adequate protection for exterior surfaces. And a good silicone treatment does not change the surface color of most materials to which it is applied, nor does it yellow.

The final type - Linseed Oil - was found effective in reducing concrete construction and maintenance costs, especially for streets, highways, and bridges. When the linseed oil composites are mixed with water they form emulsions which when applied to the concrete allow the linseed oil to form a film.

The paper ends with the major advantages of linseed oil.

C-70 "Bonding Materials to Concrete," Concrete Construction, Vol 11, No. 10, Oct 1966.

This paper lists and explains many bonding metals such as aluminum and its alloys, brass and its alloys, bronze and its alloys, chromium, etc. The article also mentions procedures a person should follow to prepare a surface for bonding. It also includes methods of degreasing metal sufaces.

One of the main objectives of many architects is the increasing tendency to use plastics.

The last section of the article deals with bonding nonmetals. It explains that these bonding agents may be applied by brush, roller, spray, trowel, screed, or squeegee. But for many jobs a combination of application methods might prove more economical.

C-71 Hosek, J., "Properties of Cement Mortars Modified by Polymer Emulsion," Proceedings, American Concrete Institute, Vol 63, Dec 1966, pp 1411-1424.

The aim of these experiments was to contribute to the understanding of the mutual influence of polymer and cement during the hardening of this combined system. Polyvinylacetate as water-emulsion was chosen as representative of polymers for all experiments.

This paper deals with the results of the experiments with polyvinylacetate-modified cement mortars; the effects of polymer admixtures on compressive, tensile, and flexural strength; on modulus of elasticity; the effect of relative humidity; and of polymer plasticizer on shrinkage. The dependence of strength on dimension of test specimens and the behavior of this mortar in water exposure and in weatherometer, rapid-cycle exposure are discussed.

Consideration of the results suggests fundamental ideas about the structure formation of polymer-cement mixtures.

C-72 Smith, M. R., "Organic Material for Bonding, Patching, and Sealing of Concrete," Significance of Tests and Properties of Concrete and Concrete-Making Materials, Special American Society for Testing and Materials Technical Publication 169-A, 1966, pp 565-571.

Concrete ranks very high among the commonly used construction materials. However, it is subject to attack by corrosive agents, including acids, salts, water, and organic solvents that wet exposed surfaces and penetrate into pores. Penetration of the concrete by water and aqueous solutions is especially important where the concrete is exposed to repeated cycles of freezing and thawing. In order to make the concrete more resistant to attack through these agencies, thereby increasing the life of the structure, it is sometimes coated with materials which protect the surface by preventing the ingress of water and other aggressive liquids into the concrete. Patches to replace defective or deteriorated areas are required frequently. Since concrete is weak in bond, the concrete to be patched is frequently coated with an adhesive that will promote bonding between the patching material and the hardened concrete.

Organic materials which have been used for bonding, patching, or sealing of concrete include epoxy resins, silicones, bitumens,

linseed oil, oil-based paints, acrylics, urethanes, vinyls, rubber-base or resin-base coatings, and polyester resins. Epoxy resin systems are the most versatile for these uses.

1967

C-73 Montle, F., Skiles, W. "How to Protect Concrete Floors (Coatings for Corrosion Resistant Surfaces)," Materials Protection, pp 29-30, Aug 1967, Carboling Co., St. Louis, Mo.

The authors examine corrosion problems encountered in concrete flooring. Methods of inhibiting corrosion with various floor coatings are discussed. Attention is given to surface preparation as aid to superior performances of floor coatings. Coatings include: Enamels, polyurethanes, epoxy and phenolic materials, polyesters, polyurethane elastomers, and modified phenolic coatings. A procedure for chemical laitance removal is included.

C-74 Perry, P. C., "Bridge Resurfaces with Epoxy Mortar," Civil Engineering (N. Y.), Vol 37, No. 11, Nov 1967, p 64.

Maintenance Dept in Washington County of Pennsylvania Dept of Highways, last fall resurfaced bridge on Route 170 with 3/8 in. thickness of epoxy mortar; epoxy compound of Guardkote 250, product of Shell Oil Co, was prepared by mixing 50 lb of equal volume mixture of epoxy ingredients A and B in a gallon pail for 4 min using electric drill with attachment for stirring; epoxy was then mixed with sand in 6 cu ft plaster mixer; weight ratio was one part epoxy to seven parts sand; mixing time was 4 to 6 minutes; batches weighed 400 lb each, enough for resurfacing 100 sq ft of roadway; pot life of mixture was about 1/2 hour.

C-75 Hallquist, A., "An Investigation on Epoxy and Polyester Resin Mortars as a Joining Material," RILEM Bulletin No. 37, (Reunion Internationale d'essais et de Recherches sur les Materiaux et les Constructions), Dec 1967, pp 233-239.

The Norwegian Building Research Institute has undertaken as a research project a study of the possibility of joining prefabricated concrete building components by means of synthetic resins. The first part of the program is a study of different mortars from which they hope to be able to evaluate their structural properties. This paper deals with an investigation on 45 different mixes of resin mortars. Three epoxies and two polyesters were used as binder in varying proportions in the mix - 15, 20, and 25% by wt. Three types of aggregates were used and of the nine 25- by 25- by 170 mm test specimen cast, 3 were cured at 20^{o} C and either 30, 65, or 85% RH for 7 days. Bending-, compressive- and splitting tensile strength were determined for all the test specimens. Using each mix, concrete cylinders, beams, and cubes were jointed together with a 5 mm joint. The test specimens were cured 7 days at 20^{o} C and 65% RH and then tested for bond-, bending-, and shear strength. To test the bond between the different mixes and reinforcing steel, mortar was filled in a steel pipe and deformed steel bars 20 mm were pushed into the pipe butting together 10 cm from the end of the pipe. When the mortar had cured for 7 days at 20^{o} C and 65% RH the strength of the joint was tested.

C-76 Lerchenthal, C. H., "Bonded Sheet Metal Reinforcement for Concrete Slabs," RILEM Bulletin No. 37, Dec 1967, pp 263-269.

The use of synthetic resins for effectively bonding metal sheet to concrete permits the exploitation of the biaxial strength of sheet metal and thereby a savings of as much as 50% in the weight of reinforcing material. Square concrete slabs were reinforced with mild steel or aluminum sheet and loaded to failure while supported on four sides. In most cases the bond between concrete and sheet reinforcement was achieved by bonding a "grip layer" consisting of stone grit and sand to the thoroughly cleaned metal surface, the adhesive being Araldite or other epoxy resins and by pouring the fresh concrete on the cured grip layer. Other bonding methods consisted in bonding the metal sheets to slabs of cured concrete and in pouring fresh concrete on sheets covered with a layer of fresh adhesives. No significant difference in the fracture behaviour of slabs reinforced by different bonding methods could be detected. The bearing capacity of square sheet-reinforced slabs supported on four sides proved to be about twice as high as that of comparable slabs similarly supported but reinforced by a conventional double layer of reinforcing bars of the same weight as the reinforcing sheet. In correctly bonded sheet-reinforced concrete slabs

fracture occurred by rupture of the sheet, by concrete failure following large deformation of the sheet in the plastic range, or under high loads on short spans, by punching shear, but not by bond failure. The behaviour of the slabs preceeding failure suggests that the sheet reinforcement also has a favourable influence on the bending rigidity of the concrete, probably through reduction of depth and spacing of cracks, i.e. increase in the effective concrete cross-section.

C-77 Beagle, C. E. "One-Half Inch Bituminous Concrete Surfaces," Highway Research Record No. 173, pp 33-54, 1967, Highway Research Board.

A comparison of yield and cost of application of one-half inch bituminous concrete surfaces on asphalt pavement and on old concrete pavement is made. Perfect Dix seal, rubberized sand asphalt, New Jersey SP-1 mix, emulsion hot mix and Maryland smooth seal are compared as to mixing, application and performance. Irregularities which occurred for each mix are recorded. One-half inch surfaces provide a smooth, quiet-riding surface, protect old, spalled and cracked concrete surfaces, and can be used instead of liquid seal on asphalt pavement.

C-78 Brink, R., Grieb, W. E., and Woolf, D. O., "Resistance of Concrete Slabs Exposed as Bridge Decks to Scaling Caused by Deicing Agents," Highway Research Record No. 196, pp 57-74, 1967, Highway Research Board.

Because of the extensive deterioration of bridge deck slabs, the resistance of sealed concrete surfaces was studied in a simulated bridge deck environment. The slabs were mounted on columns so that both the top and bottom surfaces were exposed to the air and exposed outdoors for periods up to 3 years.

Sixteen of the 17 surface coatings tested were beneficial to different degrees in increasing the resistance of concrete to surface scaling. The better results were obtained with epoxy resins, chlorinated rubber compounds, and a tar-based sealing compound. One of the coatings, an acrylic resin, did not give beneficial results.

Of the ten admixtures evaluated, two were classified as retarders, two as durability aids, five as waterproofers, and one as an accelerator. Only two of these, a durability aid and calcium chloride, significantly increased the resistance to scaling.

The tests verified the fact that resistance to scaling is a function of both the air content and water-cement ratio of the concrete, with air content having the greater effect.

Miscellaneous variables were also studied, including bituminous concrete wearing surface on concrete, depth of reinforcing steel in concrete, lightweight aggregate concrete, and expansive cement concrete.

C-79 "'White Asphalt' Being Used For Concrete Bridge Repair," Ohio Contractor, Vol 7, No. 8, Aug 1968, p 37.

Some 134 tons of "white asphalt" were recently placed on two bridge decks on I-71 in Medina County, Ohio. The Ohio Department of Highways has been using "white asphalt", a synthetic binder, for some time, mainly for resurfacing interstate bridge decks and leveling up pavement and approach slabs that have settled. The product resembles concrete in appearance but handles like asphalt. However, when placed in thin layers, cooling is much faster, and traffic can pass over it almost immediately after placement. The synthetic binder, pavebrite, contains a hydrocarbon resin which is based on a different cut of a petroleum barrel from that used for asphalt. The resin is combined with specially selected pigments and other ingredients to provide a product that can be processed and applied in the same way as ordinary asphalt. The synthetic binder is impervious to water penetration, adds very little weight to the existing bridge deck, and is the same color as the concrete pavement. However, it is considerably more expensive than other resurface products.

C-80 ACI Committee 503, "Epoxies with Concrete," Publication SP-21, 1968, American Concrete Institute, Detroit.

This symposium on "Epoxies with Concrete" includes papers on the uses, application techniques, and methods of determining physical and bonding characteristics of epoxies and

on important facets of preparing application specifications. Five of the papers included in this volume were presented at an afternoon session, Friday, 29 Oct 1966 during the annual Fall Meeting of the American Concrete Institute held in New Orleans under the sponsorship of ACI Committee 503, Adhesives for Concrete, and the ACI technical Activities Committee.

In addition to the papers presented at New Orleans, seven additional papers have been included because they deal with practical aspects and techniques of using epoxy-resin compounds with concrete.

C-81 Harding, G. N., and Duvall , B. U., "Application Specifications Guidelines," Publication SP-21, Paper No. SP 21-12, American Concrete Institute, 1968, pp 119-135.

This paper discusses items pertinent to various epoxy-resin systems applications and suggests features that should be incorporated in *application specifications*. Emphasis is placed on preparing the application specification in consonance with the particular application under consideration and in sufficient detail to avoid subsequent questioning relative to requirements for accomplishing the work. Included are appropriate remarks and recommendations covering the specifying of materials, mixes, and mixing; temperature conditions under which application is to be made; preparation of surfaces to receive epoxy-resin based systems; application of epoxy-resin systems in various use-type categories; and safety and health provisions.

C-82 McConnell, W. R., "Epoxy Surface Treatments for Portland Cement Concrete Pavements," Publication SP-21, Paper SP 21-3, pp 9-17, 1968, American Concrete Institute.

Widespread acceptance of epoxy surface treatments for pavements has been limited in part by problems associated with pinholing, poor surface appearance, and sheet detachment. Recent laboratory and field investigations promise to improve this situation markedly by use of 20 to 40-mesh rounded aggregates to stop pinholing, development of mechanical sandspreading equipment to improve appearance, and

improved techniques for deck preparation to obtain better adhesion. In addition, new application techniques permit one-step placement of pre-mixed epoxy mortars in 3/8-in. lifts, which offer numerous advantages in increased wear, improved wetting of both deck and aggregate, and greater structural integrity of the overlay treatment. These new techniques appear to be adaptable to even very large contracts. Despite existing problems, the protection afforded by epoxy treatments, together with the combination of thin courses and long life, continue to indicate a permanent place for these treatments in the highway industry.

C-83 Scales, G. M., "Epoxy Resins," Publication SP-21, Paper No. SP 21-1, pp 1-4, 1968, American Concrete Institute.

The name, origin, history, and development of epoxy resins over the last 20 years are described. While early developments made use of the properties as adhesives, electrical insulation, and protective coatings, these resins are now used extensively in the building industry. In order to use the epoxy, the components of the resin and hardener must be well mixed and then the resulting liquid gradually gets warm, solidifies, and cools to form a hard, infusible solid.

C-84 Schutz, R. J., "Epoxy Resin Adhesives for Bonding Concrete to Concrete," Publication SP-21, Paper No. Sp 21-4, pp 19-28, 1968, American Concrete Institute.

The history of epoxy-resin adhesives for bonding concrete and other materials to concrete is reviewed. During the short history of commercial use, epoxy-resin adhesives have evolved into two basic types: those capable of bonding plastic or hardened concrete to concrete, and faster-curing systems developed for bonding hardened concrete or other rigid structural materials to concrete. Experience has shown that proper surface preparation determines the success of concrete bonding. Mechanical abrading has proven the most reliable method of surface preparation; acid washing may lead to variable results. Although little difficulty has been experienced in the field, epoxy-resin adhesives may cause sensitization of individuals coming in contact with them. Precautions and toxicological details are covered. At present, there are no standard test methods for evaluating

epoxy-resin adhesives for use with concrete although the diagonal-tension test has proven reproducible. The writing of standard specifications for these adhesives awaits the acceptance of standard test procedures.

C-85 Steinberg, M., Kukacka, L., Colombo, P., Kelsch, J., Monowitz, B., Dikeou, J., Backstrom, J., Rubenstein, S., Concrete Polymer Materials, First Topical Report, BNL 50134 (T-509) and USBR General Report 41, 1968.

The preparation, testing, and development of concrete-polymer composites as improved materials of constuction are under investigation in a joint program being carried out by the Radiation Division of Brookhaven National Laboratory and the Division of Research of the U. S. Bureau of Reclamation with the support of the Division of Isotopes Development of the U. S. Atomic Energy Commission, the Office of Saline Water, and the U. S. Bureau of Reclamation. The studies include the development of methods of preparation of both preformed and premixed concrete-polymer composites. The preparation techniques for preformed concrete consist of drying, evacuating, monomer soaking, coating, and in situ polymerizing of the monomer either by Co^{60} gamma radiation or by thermal-catalytic initiation, or by a combination of both. For the premix concrete, either part of the water is replaced with monomer or monomer is added to the fresh concrete mix, and the mix is subsequently radiation or thermally treated.

It has been shown that preformed air-entrained concrete and mortar can be fully impregnated with a monomer and the monomer polymerized in situ either by radiation or by thermal-catalytic techniques. Monomers tested in survey experiments included ethylene, ethylene-SO_2, vinyl acetate, acrylonitrile, methyl methacrylate, styrene, styrene-acrylonitrile, 10% trimethylolpropane trimethylacrylate-methyl methacrylate, polyester-styrene, and epoxy-styrene. The ethylene gas produced a fine white powder dispersed through the void volume of the concrete. The liquid monomers gave a continuous hard deposit through the concrete.

The highest degree of polymer loading obtained with air-entrained concrete containing type II cement is 6.7% by weight of the unimpregnated concrete or ≈ 13% by volume. This comes close to complete filling of the available void volume in this type of concrete.

An extensive series of tests has been carried out with polymethyl-methacrylate impregnated concrete and polystyrene impregnated concrete. The improvement in structural properties has been found to be an increasing function of the weight loading of the concrete. The degree of weight loading depends on the dryness of the concrete.

One set of conditions to obtain maximum polymer loading with methyl methacrylate is to ovendry the concrete specimen to constant weight at temperatures of 221° F (105° C) or higher, evacuate the air to < ≈3 in. Hg, absolute pressure, soak in liquid monomer, wrap in polyethylene film, and irradiate at ambient temperature to a dose of 1.5 megarads at a dose rate of 2.5 by 10^5 rads/hr. Polymerization can also be obtained by heating the impregnated concrete to 167° F (75° C) for 2 hr with 2% benzoyl peroxide catalyst added to the monomer. Cylindrical specimens up to 6 in. diam by 12 in. long have been fully impregnated. A summary of the properties for maximum loading with methyl methacrylate is given in Table 1.

Remarkable improvements in properties compared with those of control specimens of untreated concrete have been obtained as follows:

(a) Compressive strength increases of 285% over control or a factor of almost four times the compressive strength of the control.

(b) Tensile strength increases of 292%.

(c) Modulus of elasticity increases of 80%.

(d) Modulus of rupture increases of 256%.

(e) Flexural modulus of elasticity increases of 44%.

(f) Freezing and thawing improved by >300%.

(g) Hardness-impact ("L" hammer) increases of 73%.

(h) Water permeability decreases to negligible values.

(i) Water absorption decreases of as much as 95%.

(j) Reduction of corrosion by distilled water and sulfate brines to negligible values compared with the severe attack observed on the control specimens.

The coefficients of expansion, specific heat, and diffusivity have been measured. Resistance to abrasion, cavitation, soluble sulfates, and acid corrosion has shown significant improvement.

Methyl-methacrylate impregnated concrete-polymer specimens subjected to creep tests exhibited an expansion under sustained load (negative creep). This is the opposite of

the normal contraction in length (positive creep) of ordinary concrete. Further investigation of this highly unusual phenomenon of negative creep is necessary, since this property could have a significant influence on the design of concrete-polymer structural and prefabricated members.

Thermal-catalytically polymerized concrete-polymer had strength values 7 to 15% lower than Co^{60} gamma-radiation polymerized concrete-polymer. Polystyrene impregnation of concrete gave 30% lower strength values than polymethyl methacrylate. It was also noted that cracking of the concrete occurred in undried specimens impregnated with styrene and polymerized by radiation. There was no cracking with styrene impregnation of dried and irradiated concrete or with styrene impregnation of dried and undried thermally treated concrete.

Radiation and thermal treatment of unimpregnated concrete gave no improvement in structural properties. The improvement in properties is thus attributed to polymer impregnation.

A series of test specimens with cross-linked polymethyl methacrylate has been prepared. The test results are not yet availabe.

In the case of premixed concrete-polymer preparations, improvements in compressive strength and water absorption were obtained with styrene and acrylonitrile monomer additions. The maximum improvement (87% in compression with acrylonitrile) was much lower than that with impregnated. preformed concrete. In the case of methyl methacrylate premixed, there was a marked decrease in compressive strength. Substitution of methyl alcohol for water inhibited the hardening of concrete.

High-strength OSW concrete (type V cement, air-entrained with fly ash and aggregate) impregnated with methyl methacrylate gave the highest value of compressive strength, 22,630 psi, equivalent to a 164% improvement over untreated OSW concrete.

The fine structure of the concrete-polymer material is being examined by optical and electron microscopy and petrographic techniques. Fundamental studies are in progress to obtain an understanding of the bonding of the polymer to the concrete on a micro scale. These studies show that for preformed concrete at higher loadings, the impregnation was fairly complete and the polymer coated most of the internal surfaces of the void passages in the concrete. In the premix concrete the polymer distribution varied from poor to good.

A generalized cost comparison with other common construction materials, with the ratio of the estimated unit material cost of the finished product to its strength used as an index, indicates that concrete-polymer (polymethyl methacrylate) in compression is far superior to concrete alone and to plastic alone, as well as to steel and aluminum. However, in tension the concrete-polymer is second best to steel and aluminum but better than either concrete or plastic alone.

In terms of durability (resistance to freeze-thaw, water absorption, corrosion resistance, etc.), concrete-polymer offers a large improvement over concrete alone. The significant improvement in properties obtained with relatively low concentrations of low-cost monomers gives the material a definite economic potential.

Several possible applications of concrete-polymer are mentioned. These include concrete-polymer sewer and pressure pipe, building materials for housing and for underwater structures, corrosion-resistant concrete in desalination plants, and antifragmentation concrete. The composite appears to have low maintenance qualities and high aesthetic value. The applications of this material await the combined ingenuity of design and process engineers in arriving at economically attractive situations.

Recommendations are made for continuing the development of concrete-polymer materials by investigating preparation techniques, testing different types of monomer in combination with different types of concrete, determining concrete-polymer properties at elevated temperature, and obtaining a fundamental understanding of the composite structure.

C-86 Whitesides, G. W., "Stresses in Epoxy Compounds for Portland Cement Concretes," Publication SP-21, Paper No. Sp 21-10, pp 93-100, 1968, American Concrete Institute.

This paper is concerned with a study of stresses in epoxy compounds induced by curing and thermal shrinkage, and their relative effect on epoxy overlays and repairs to portland cement concrete. The study shows that the principal cause of distress in epoxy overlays and laminates results from autogenous (curing) shrinkage, since there is sufficient elongation in epoxy compounds designed for use with portland cement concrete to accommodate stress that results from the difference in the coefficient of thermal expansion of the epoxy compound and that of portland cement concrete. It also shows that autogenous (curing) shrinkage can be kept within

acceptable limits. It is the intent to emphasize that, while tests presently in use for epoxy compounds for portland cement concrete may adequately define the properties of the epoxy compound, they do not necessarily predict function in the epoxy compound and portland cement concrete "entity." Research based on this concept of "entity" should lead to acceptance tests which predict the service life of an epoxy compound repair of portland cement concrete. One such test is included.

<u>1969</u>

C-87 Bureau of Reclamation, "Concrete and Epoxy Materials Compared - Load Properties, Durability, and Volume Change," Report No. C-1313, Feb 1969, Denver, Colorado.

Laboratory tests of the physical properties of epoxy mortars and epoxy concretes were conducted to determine the structural compatibility of these materials with portland cement concretes. Tests indicate good structural compatibility of physical properties except for thermal expansion and other volume changes. Epoxy mortars and concretes possess almost no measurable creep at 0^{o} F, but have compressive creep and elasticity characteristics at 73^{o} F very close to portland cement concrete. Mixes employing minimum volumes of epoxy have thermal expansion values about 2-1/2 times the expansions of portland cement concretes; larger amounts of epoxy increase expansion. No shrinkage after the initial hardening was measured in the epoxy mixes, but portland cement concrete does shrink and expand during moisture changes. Abrasion resistance and unit weight properties are similar. Mortars and concretes using epoxy resin binder are much stronger than cement concretes in compression, flexure, and tension; are much more resistant to breakdown in freeze-thaw conditions; and absorb much less water during soaking. All physical properties tested and compared indicate that epoxy mixes using small amounts of resin are more compatible with portland cement concrete than mixes containing large amounts.

C-88 Geymayer, G. G., "Use of Epoxy or Polyester Resin Concrete in Tensile Zone of Composite Concrete Beams," Technical Report C-69-5, Mar 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report describes the results of an investigation into the feasibility of combining the high compressive strength of portland cement concrete and the superior tensile strength of epoxy or polyester resin concrete into a composite beam. This would increase the beam's flexural strength and improve the corrosion protection for the reinforcement at large deflections by eliminating tensile cracks. The report describes in detail the development of high-strength resin concrete mixtures. Also included are the results of third-point loading tests of 12 reinforced and unreinforced composite beams with 1-1/2- and 3-in.-thick layers of epoxy and polyester resin concretes. These results are compared with results of tests of two reference beams without resin concrete layers and with analytical results. The study led to the following principal conclusions:

a. Properly designed resin concrete layers at the tension face of concrete beams can be used to moderately increase the strength and rigidity of reinforced concrete beams, or to upgrade the flexural strength of unreinforced beams by a factor of two to three.

b. More important than their influence on strength is the ability of resin concrete layers to provide a noncracking moisture barrier or corrosion protection practically up to beam failure.

c. The epoxy resins appeared to be more suitable for this application than the polyester resins investigated due to lower shrinkage and exotherm as well as higher tensile strength and tensile strain capacity.

d. In proportioning resin concrete mixtures, early attention should be directed to properties other than strength (such as shrinkage, exotherms, coefficient of thermal expansion, creep, sensitivity to environmental factors, etc.).

C-89 Drisko, R. W., "Investigations of Underwater-Curing Epoxies," Report No. TR-622, Apr 1969, Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Laboratory and field studies were conducted on both viscous underwater-curing epoxies (splash-zone compounds), which must be applied by hand, and brushable underwater-curing epoxies. The splash-zone compounds are more easily applied than the brushable products and can be used to advantage at the present time by NFEC field activities. Brushable underwater-curing epoxies can be applied with relative ease in the laboratory but are difficult to apply in the field.

C-90 Rooney, H. A. and Shelly, T. L., "Thin Resinous and Aggregate Overlays on Portland Cement Concrete," Research Report No. M & R 635121, Jun 1969, Materials and Research Department, California State Division of Highways.

Fifteen different formulations of resinous binders for overlays have been evaluated. Seven were applied near Sacramento where freezing rarely occurs and eleven were applied at Kingvale near Donner Summit at about 6,000 feet where severe snowplow and chain wear is encountered. All but one of the binders tested near Sacramento are in good condition after three and one-half years of service. At Kingvale one polyester seal coat applied in three layers over an epoxy primer is showing good durability but low skid resistance after nearly three years of service. Polyester overlays without an epoxy primer failed during the early part of the first winter. Single layer epoxy seal coats, about 1/3-in.-thick failed in one year or less. Two double-layer systems, each about 1/4-in.-thick, lasted for two years.

C-91 Scott, A., "Epoxy Resins in Structures," Engineering, Vol 207, No. 5382, Jun 1969, p 879.

The author gives a brief description of the uses of Epikote as a grout in the laying of rails for the Goliath crane in Belfast. This and other examples of the uses and properties of epoxies was given at a symposium arranged by Shell Ltd.

C-92 Dikeou, T. J., Kukacka, L. E., Backstrom, J. E., and Steinberg, M., "Polymerization Makes Tougher Concrete," Proceedings, American Concrete Institute, Journal, Vol 66, No. 10, Oct 1969, pp 829-839.

Reports on a study of the feasibility and techniques of impregnating and in-place polymerizing of liquid monomers in preformed concrete, and the use of monomers in a fresh concrete mix, followed by polymerization. Two methods of initiating polymerization - gamma radiation and thermal-catalytic - are being studied. Studies include development of impregnation techniques and determination of the effects of various polymer loadings on resultant properties. The

radiation technique produces greater improvements in properties than does the thermal-catalytic method.

Dramatic improvements in concrete properties resulting from the impregnation-irradiation with methyl methacrylate are discussed. For example, compressive and tensile strength and modulus of rupture are increased by 256 to 290 percent; water permeability decreased to negligible values; water absorption decreased as much as 95 percent; and resistance to abrasion, cavitation, freezing and thawing, distilled water, soluble sulfates, and acid showed significant improvements.

C-93 Dikeou, J., Backstrom, J., Hickey, K., Rubenstein, S., Jones, C., Steinberg, M., Kukacka, L., Colombo, P. Austkem, A., Monowitz, B., Concrete-Polymer Materials, Second Topical Report, BNL 50218 (T-560) and REC OCE 70-1, 1969.

The research program to develop concrete-polymer composites as improved materials of construction is a continuing effort being conducted jointly by the Radiation Division of the Department of Applied Science, Brookhaven National Laboratory, and the Division of Research of the Bureau of Reclamation. The basic program is supported by the Division of Isotopes Development of the U. S. Atomic Energy Commission, and the Office of Saline Water and the Bureau of Reclamation of the U. S. Department of the Interior. The program was initiated in 1967, and work completed through June 1968 was described in the First Topical Report, issued in January 1969. The present report describes work accomplished through June 1969.

Experiments were continued to determine the structural and durability properties of monomer-impregnated concrete being considered for normal temperature applications. The structural properties of concrete impregnated with acrylonitrile and with methyl methacrylate (MMA) containing 10 wt% trimethylolpropane trimethacrylate (TMPTMA) are described here. Testing of the durability of these monomers has been started. The work with MMA and styrene was continued during the year.

Significant improvements in structural properties were obtained. The concrete-MMA + 10 wt % TMPTMA Composite showed the highest compressive strength observed to date. Compared with a control strength of 5270 psi, a maximum strength of 22,490 psi was obtained for a specimen containing 6.3 wt % monomer polymerized by radiation. This is an increase over

that of the controls of 327%. Thermal-catalytic polymerization of the above mixture resulted in a maximum strength 11% lower than that obtained by radiation (20,010 vs 22,490 psi), even though the polymer content was ≈13% greater (7.1 vs 6.3%).

Acrylonitrile-impregnated specimens exhibited a maximum compressive strength of 14,890 psi, corresponding to a 180% increase over that of the controls. These results are lower than those obtained for MMA + 10 wt % TMPTMA and for MMA alone, but greater than those for styrene.

Comparable trends were obtained for tensile and flexural strength. A tensile strength of 1710 psi was measured for the MMA + 10 wt % TMPTMA mixture polymerized by radiation. This is an increase of 310% over the control value (416 psi) and ≈5% greater than the previous high obtained with MMA (1627 psi). A maximum tensile strength of 1280 psi was obtained for acrylonitrile-impregnated specimens polymerized by radiation.

A comparison was made of the compressive and tensile strengths obtained for radiation and thermal-catalytic polymerization. The results indicate that with the four monomer systems studied, polymerization by radiation results in greater strengths than are obtained with thermal-catalytically produced composites. Differences, generally of the order of 12 to 17%, were observed. With styrene-impregnated specimens, differences of ≈35% were obtained.

Remarkable improvements in durability properties were obtained. In general, MMA-impregnated specimens showed the greatest improvement, acrylonitrile, the least. Their durability properties are compared with those of the control specimens below.

a. Freeze-thaw durability improved by >366% (760% for one survey series specimen).

b. Chemical attack by sulfate brines reduced to negligible values compared with the severe attack observed on the control specimens.

c. Resistance to chemical attack by 15% hydrochloric acid increased by >318%.

d. Water permeability decreased to negligible values.

e. Water absorption decreased by as much as 95%.

The durability properties appear to be dependent on the polymer content; whether polymerization is carried out by radiation or by thermal-catalytic means seems to make little difference.

The results for a series of test specimens prepared with monochlorostyrene will soon be available.

The structural properties of steel-reinforced concrete-polymer materials are being determined. Pull-out bar tests indicate bond strengths up to 700 psi for MMA-impregnated specimens, compared with 238 psi for the controls. This corresponds to an increase of 194%. Concrete specimens containing 2 vol % of randomly oriented steel fibers and impregnated with 9.7 wt % MMA exhibited compressive strengths up to 23,828 psi, an increase of 383% over the value for the unimpregnated reinforced control and of 477% over that for the nonreinforced control. The impregnation of fiber-reinforced slabs increased the modulus of rupture to as much as 3000 psi, which corresponds to improvements of 418 and 173% over those for the nonreinforced and reinforced controls, respectively. Tests conducted on impregnated mortar containing 8 vol % steel fiber indicated that the ultimate flexural strength of plain mortar was increased by a factor of 15 by the addition of fiber and impregnation with MMA.

The impregnation of standard concrete building block indicated improvement in compressive strengths by as much as 345%.

The impregnation of light-weight concrete ($\approx$56 lb/ft^3) containing foamed-glass aggregate resulted in compressive strengths of $\approx$5800 psi for samples containing 17 wt % polymer. Compared with a control strength of 1000 psi, this represented an improvement of 480%.

Tests were made to estimate the resistance of concrete-polymer to penetration by caliber 30 AP, M2 projectiles. The results indicate that, compared with the controls, 8 and 40% greater energy was required to penetrate 2- and 4-in.-thick sections of concrete-polymer, respectively.

Soil-cement specimens were impregnated with MMA with use of premix and precast techniques. Two types of soil, silt, and silty sand, were used. The impregnation and radiation polymerization of precast specimens of silty sand containing 10% cement resulted in significant improvements in properties. Compared with controls, an increase in compressive strength of 230% and a reduction in water absorption of 97% were obtained. Improvements in freeze-thaw durability were also obtained. Premix-type specimens polymerized by thermal-catalytic methods showed reduced strength and durability properties. Similar results were obtained with samples containing silt and 12% cement.

The mechanical properties of concrete-polymer materials at elevated temperatures are being investigated. Four monomer systems have been screened for use in concrete-polymer having potential as a material of construction for flash

distillation units in water desalination plants. The monomers were selected on the basis of high-temperature softening points. Cross-linking agents and thermosetting monomers are being used. High strength OSW-type concrete impregnated with a 60 wt % styrene + 40 wt % TMPTMA mixture showed the greatest strength {19,720 psi at 76° F (24° C)} and the smallest decrease in strength at elevated temperatures {18,600 psi at 290° F (143° C)}. The latter value is 148% higher than that for the control at the same temperature. Based upon the results of the screening tests, the 60 wt % styrene + 40 wt % TMPTMA mixture and a 90 wt % diallyl phthalate + 10 wt % MMA mixture were chosen for continued evaluation.

A theoretical and experimental investigation to determine the mechanism by which the presence of polymer in concrete increases the strength has been started. Models based upon theory for particulate-filled systems have been developed which appear to correlate with the experimental strength improvements obtained.

The microstructure of the concrete-polymer material is being examined by optical, electronmicroscopic, and petrographic techniques. Photographic evidence that the polymer forms a continuous, three-dimensional structure of interconnected fibers which represents the structure of the connected porosity of the cement has been obtained.

The measurement of sonic velocity is being investigated as a nondestructive quality control procedure for determining the strength of concrete-polymer materials.

The potential application for concrete-polymer pipe is being evaluated. Sixty sections of polymer-impregnated concrete draintile have been prepared and are being field-tested in a highly saline soil. A program has been initiated in cooperation with the American Concrete Pipe Association for the evaluation of 12- and 24-in.-diam unreinforced and reinforced pipe.

Several governmental agencies have joined the program in a cooperative effort to evaluate applications of specific interest: The U. S. Department of Agriculture is considering the use of steel-fiber reinforced concrete-polymer in thin panels and tilt-up walls for low-cost housing construction; the Naval Civil Engineering Laboratory is conducting exploratory experiments on spherical concrete hulls for underwater applications; the Bureau of Public Roads is interested in increasing the durability or roads and bridge decking and in the use of light-weight concrete for breakaway lampposts; and the U. S. Army Corps of Engineers is interested in a variety of applications, including storage bunkers and soil stabilization.

C-94 Stewart, P. D. and Shaffer, R. K., "Investigation of Concrete Protective Sealants and Curing Compounds," Highway Research Record No. 268, pp 1-16, 1969, Highway Research Board.

Thirty-two separate products and control mixes were evaluated in a four-phase testing program. The purpose of the first phase was to evaluate the ability of penetrating-type sealants to protect concrete against the deteriorating action of freeze-thaw cyles. Concrete specimens measuring 1 ft square were coated with various product applications, filled with a chloride solution (five percent) and subjected to 100 cycles of freeze-thaw. Surface scaling was measured at intervals using a numerical value system.

In the second phase, ten products recommended as combination curing-sealing compounds were tested. The curing properties were determined by comparing the compression strengths of product-cured and moist-room cured cylinders. Slab specimens, cured with each product, were subjected to freeze-thaw tests.

In the third phase, a test method was designed to measure the depth of sealant penetration into the surface of a typical concrete slab. A fluorescent material was mixed with several products before application and the penetration was measured by linear traverse equipment using ultraviolet light.

The fourth phase was devoted to the design of equipment and methods to determine the effect of sealants on bond between concrete and bituminous overlays. The method was designed to measure the force required to shear the bituminous portion of the specimen from the treated concrete.

1970

C-95 ACI Committee 504, "Guide to Joint Sealants for Concrete Structures," Proceedings, American Concrete Institute, Journal, Vol 67, No. 7, Jul 1970.

Most joints, and some cracks in concrete structures, require sealing against the adverse effects of environmental and service conditions. This report is a guide to better understanding of the properties of joint sealants and to where and how they are used in present practice.

Described and illustrated are: the functioning of joint sealants; required properties, available materials and applicable specifications for field-molded sealants and pre-formed sealants such as waterstops, gaskets or compression seals; determination of joint movements, widths, and depths; outline details of joints and sealants used in general structures, fluid containers and pavements; methods and equipment for sealant installation including preparatory work; performance of sealants; and methods of repairing defective work or maintenance resealing. Finally, improvements needed to insure better joint sealing in the future are indicated.

C-96 Davydov, S. S., Solomatov, V. I., Shvidko, I. Ya, "Epoxy Polymer Concrete," Gidrotekhnicheskoe Stroitel'stov, No. 9, Sep 1970, pp 41-43.

The paper deals with a thorough study of the properties (primary resistance to water, creep, long term strength, and adhesion) of epoxy polymer concrete. With respect to water protection, the paper covers reduction in strength, water absorption, moisture conductivity and bonding characteristics to ordinary concrete.

C-97 Rajagopalan, K. S. and Chandrasekaran, S., "Studies on Protective Coatings for Concrete," Indian Concrete Journal (Bombay), Sep 1970, pp 411-416.

The paper presents a two part experiment to determine the effectiveness of different coatings in the prevention of corrosion of steel and the deterioration of concrete from penetration of water and chemicals. The first portion was the determination of the most deleterious solution to the concrete and the second phase consisted of testing 43 different coatings under this adverse condition.

C-98 Steinberg, M., Kukacka, L. E., Colombo, P., Auskern, A., and Pike, R. G., "Concrete-Polymer Materials for Highway Applications," Report No. BNL-15395, Sep 1970, Brookhaven National Laboratory, Upton, N. Y.

Work to date has indicated that an increase in compressive strength of about three-fold can be obtained with both high and low quality concretes by impregnating the concrete with methyl methacrylate monomer and then polymerization by either radiation or thermal catalytic means. The strength of lightweight insulating concrete in some cases has been increased from a strength of 100 psi to about 4,000 psi. Tests also indicate that creep is less than one-tenth that of the control concrete. The abrasive resistance of the concrete has been improved by a factor of about two. Impregnation of structural lightweight concrete has given compressive and tensile strengths of 78,000 and 2,000 psi, respectively. Efforts are now being made to prepare specimens of greater uniformity. Preliminary design studies using computer-coded finite element analysis were made to determine the feasibility of using concrete-polymer materials for precast bridge decks and breakaway lampposts. Based on the limited data on properties, both applications appear attractive. Additional data under static and dynamic test conditions are required before a detailed structural design and cost estimate can be made.

C-99 Causey, F. E., "Evaluation of Materials for Cavitation Resistance," Oct 1970, Bureau of Reclamation, Denver, Colo.

Describes cavitation testing of potential protective coating materials that can be field-applied to steel and concrete surfaces. Report evaluates performance of 71 coated specimens, representing 21 classes of materials.

C-100 Kozlowski, A. B. and Butler, D., "Epoxy and Similar Mortars," Dec 1970, International Road Federation.

Epoxy mortar materials are being developed for the repair and improvement of concrete roads and pavements, particularly the arrises of joints. Also being developed are screeds for repair or waterproofing applications, particularly for bridge surfaces, and pitch-epoxy nosing for bridge and other joints.

C-101 Gross, W., "Applications Manual for Paint and Protective Coatings," 1970, Binks Research and Development Corporation, Boulder, Colo.

This manual gives an outline of the composition, outstanding properties, recommended usages, solvents and thinners, and application conditions for the major generic types of paints and coatings.

1971

C-102 McKeel, W. T., Jr. "Evaluation of Epoxy Compounds as a Material for Patching and Protecting Concrete," Report No. VHRC 70-R33 Mar 1971, Virginia Highway Research Council, Charlottesville.

The report summarizes the results of a study of the use of epoxy compounds in the shallow surface repair and sealing of concrete bridge decks. The research effort which concentrated on the use of epoxy resin systems as bonded overlays included evaluations of test strips of seven materials on two structures in northern Virginia, supplemented by observations of the findings of approximately fifty full-scale applications. The wearing of thin bonded epoxy overlays exposed to traffic, as manifested in the loss of both skid resistance and protection afforded the underlying concrete, is the definitive factor in the service life of the application. The resistance to wearing of the exposed overlays observed in this study was generally disappointing and the use of an asphaltic wearing course to protect the epoxy sealcoat is considered essential to the continued effectiveness of an overlay application. The skid resistance afforded by an exposed epoxy overlay must be considered a limiting factor in its service life. The study indicates that, regardless of the type of deslicking aggregate employed, unprotected epoxy overlays suffer a continuing decline in skid resistance under exposure to traffic. Such applications, particularly those containing coal tar modified epoxy resin systems which tend to lose aggregate and polish, should be evaluated periodically for signs of loss of skid resistance.

C-103 Furr, H. L., and Ingram, L., "Bond and Durability of Concrete and Resinous Overlays," Report RR-130-5, Apr 1971, Texas Transportation Inst., College Station, Tex.

Tests were made on portland cement and resinous concrete overlays to determine their suitability as overlays for deteriorated concrete bridge decks. Direct shear strengths of overlays bonded with epoxy, portland cement grout, and latex modified cement grout were compared with those applied with no bonding agent. Freeze-thaw tests were made to determine durability of bonding agents and of overlay concretes. Load tests were made on 8 ft span beams to determine the stiffening effect of overlays and the effect of repeated loadings on overlaid beams. Durability was studied further by gradually lowering laboratory temperature to 20^{o} F during periods of repeated load applications.

C-104 "Controlling Cracks with Plastic Joints," Concrete Construction, May 1971, p 185.

Random cracks in concrete slabs can be minimized by use of plastic contraction joints and careful finishing. Method, tools, and procedures presented.

C-105 "Polymer Concrete. . . Another Major Plus for the Most Versatile Construction Material," Concrete Construction, May 1971, pp 173-175.

Compared to ordinary concrete, polymer concrete exhibits the following advantages: four times the compressive strength, modulus of elasticity increased 80 percent, modulus of rupture improved 256 percent, freeze-thaw durability increased 300 percent, hardness-impact increased 73 percent.

C-106 Yeager, J. C., "Wear-Resistant Concrete Floors," The Construction Industry Bulletin, May 1971, pp 13-15.

The author, field director of technical services for the Concrete Industry Board, presents a suggested specification for hard, wear-resistant concrete floors. The specification details the use of iron aggregate and natural aggregate dry-shake material and proposes standards for curing the concrete.

C-107 Auskern, A. and Horn, W., "Some Properties of Polymer-Impregnated Cements and Concretes," Journal, American Ceramic Society, Vol 54, No. 6, Jun 1971, pp 282-285.

Polymer-impregnated cement and polymer-impregnated concrete were prepared by vacuum-filling cured and dried cement and concrete with a low-viscosity monomer and polymerizing the monomer by a thermal-catalytic of gamma-radiation method. The strength and durability of the products are significantly better than those of the unimpregnated materials. Some observations involving monomer loading, polymerization, and polymer distribution are discussed. A simple model is presented which describes the variation in strength of cement and concrete with polymer content; the model is compared with experimental results.

C-108 Derrington, C. F. and Pepper, L., "Survey of Applications of Epoxy Resins for Civil Works Projects," Technical Report C-71-1, Jul 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Includes summary of uses and types of applications, procedures, performance since 1959 and serves as guide for use of epoxy compounds with concrete. Some 80 applications of epoxy resins discussed, under these general headings: bonding fresh to hardened concrete, patching and repairing cracks, applying protective coating, waterproofing and sealing joints, bonding metal to hardened concrete, coating for erosion resistance, bonding hardened concrete to hardened concrete.

C-109 Mayberry, D., "Linseed Oil Emulsion for Bridge Decks," Concrete Construction, Sep 1971, pp 383-384.

Curing wet concrete with linseed oil spray techniques is believed to retard concrete deterioration and reduce spalling under winter deicing salts. Reports tests conducted by Oklahoma Highway Department bridge engineers, refers to Kansas experience where linseed oil emulsion used on bridges of all sizes under conditions varying from freezing to hot and windy has almost entirely eliminated deck curing problems.

C-110 "Fast-Fix C-2 Cement," Technical Bulletin No. 5, Oct 1971, Custom-Crete, Inc.,

Fast-Fix C-1 cement was developed for the Air Force so they could repair bomb-damaged runways with concrete and have traffic on it in one hour. Long-term durability was not a criteria in its design. However, its fast-setting, early-strength characteristics made it very desirable for commercial repairs on highways, utilities and some new construction.

Fast-Fix C-2 was developed to impart these desirable rapid-use characteristics, plus the long-term durability of portland cement concrete. A status report on this account is presented discussing known characteristics such as mix design, setting times, durability, strength and various special procedures to follow.

C-111 "Oklahoma Requires Linseed Oil Curing Compound on Bridge Decks," Public Works, Oct 1971, pp 74-75.

Bridge Division of Oklahoma's Department of Highways demonstrates use of linseed oil emulsion as curing agent on concrete bridge decks for state and federal officials. Treatment also furnishes first layer of linseed oil applications, providing immediate brine protection. Similar experiments at Witchita, Kansas, have proven effectiveness of the linseed treatment.

C-112 "Thin Polymer Concrete Overlay Tested," Engineering News-Record, Oct 21, 1971, p 22.

A 3/4-inch-thick polymer concrete with 87 percent aggregate content is being tested at the New Jersey entrance to the Lincoln Tunnel. The material is produced by Concrete Development Corporation, a subsidiary of H. B. Zachry Co., San Antonio.

C-113 "Sealing Membrane Applied to Bridge Deck," Construction Digest, 18 Nov 1971, p 48.

St. Louis, Missouri, overpass given woven glass fabric and rubberized coal tar membrane between deck and wearing surface to protect against moisture penetration. Describes materials, application, expectations.

C-114 Dikeou, J., Cowan, W., DePuy, G., Smoak, W., Wallace, G., Steinberg, M., Kukacka, L., Auskern, A., Colombo, P., Hendrie, J., Monowitz, B., Concrete-Polymer Materials, Third Topical Report, REC-ERC-71-6 and BNL 50275 (T-602), 1971.

Investigations of concrete-polymer materials as of June 1970 under a joint program of the Bureau of Reclamation, Brookhaven National Laboratory, Atomic Energy Commission, and Office of Saline Water are reported. Three materials being investigated are: (1) polymer-impregnated concrete (PIC-precast portland cement concrete impregnated by a monomer system which is subsequently polymerized in situ); (2) polymer-cement concrete (PCC-monomer is added during mixing of portland cement, water, and aggregate, followed by polymerization); and (3) polymer-concrete (PC-a composite formed by polymerizing a monomer and aggregate mixture). Investigations indicate that the most successful concrete-polymer material for construction is PIC; however, present studies are including PC and PCC because of potential applications if feasible fabrication methods can be developed. Compared to conventional concrete, PIC shows impressive improvements in strength and durability. Tests show that PIC made with ordinary concrete has essentially the same properties as PIC made with a more expensive high-strength concrete. Applications for PIC being investigated are desalting plants, draintile, culvert and sewer pipe, beams and wall panels in housing, bridge decks, roads, luminaries, and underwater structures. Recommendations are given for future work.

1972

C-115 Kalousek, G. L., Porter, L. C., and Benton, E. J., "Concrete for Long-Term Service in Sulfate Environment," Cement and Concrete Research, Jan 1972, pp 78-89.

Presents data on concretes soaked continuously in 2.1 percent sodium sulfate solution, alternatively soaked and

dried in study to predict service life. Varying types of cements, admixtures utilized in samples; findings indicate good life expectancy. Suggests revision of present-day specifications for sulfate resisting concrete.

C-116 Spellman, D. L., Stoker, J. R., Woodstrom, J. H., Sundquist, C. R., and Squires, B. T., "Patching and Grouting Materials for Portland Cement Concrete," Jan 1972, California State Division of Highways,

Evaluation of 19 commercial products sold as portland cement concrete patching compounds compared to Type III cement mortar. Properties tested included set time, expansion when soaked 24 hours, drying shrinkage, percent chlorides, percent sulfate, abrasion resistance and compressive strength at one hour, four hours, one day, three days, and twenty-eight days.

C-117 "Bridge Resurfaced with Latex-Modified Mortar," Public Works, Feb 1972, pp 63-64.

Dow Paving system of portland cement mortar modified by addition of latex emulsion used in bridge deck repair at West Lafayette, Indiana. Finish was machine consolidated, providing smooth surface. Curing methods discussed.

C-118 McCaul, C. and Geld, I., "Corrosion and Coatings Test Program of the NYC Board of Water Supply," Materials Protection and Performance, Feb 1972, pp 41-44.

New York program involves long-term corrosion and deterioration tests in natural environments to evaluate resistance of generic materials. Concrete tunnel linings among materials studied.

C-119 "Sharp Increase in Use of Liquid-Applied Membrane Waterproofing Indicated," Building Design and Construction, Apr 1972, p 57.

Use of liquid-applied membrane waterproofing grew from about five million square feet in 1968 to about 20 million in 1971, according to study; ease of application, integrity of finished surface appeal; vices of sheet membranes contribute to increased use of liquid types.

C-120 Kuenning, W. H., "How to Repair Cracks by Grouting with Epoxy Resin," Concrete Construction, May 1972, pp 221-222.

Repair of concrete places physical and chemical requirements on numerous categories of epoxies that are available. Physically, epoxy should have low viscosity, be capable of bonding to moist concrete; chemically, needs sufficient pot life to permit convenient handling, a minimum of 30 minutes before gelling; no solvent should be included in formulation and not more than one percent of reactive diluent. Discusses how to repair.

C-121 Gebhart, L. R., "Experimental Cationic Asphalt Emulsion Grouting," Journal of the Soil Mechanics and Foundations Division, Proceedings, American Society of Civil Engineers, Vol 98, No. SM9, Sep 1972, pp 859-868.

As the reservoir filled behind Morrow Point Dam, leakage increased around the limits of the cement grout curtain on the left abutment. A short distance downstream, leakage into the underground power plant drainage tunnel reached 429 gpm. A cationic asphalt emulsion grout, triggered with a hydrated lime slurry, was chosen to plug the large flowing water channels. Injection of 10,100 gal of asphalt emulsion reduced leakage into the power plant drainage tunnel by approximately 65%. The long-term effectiveness of the asphalt emulsion injection was difficult to evaluate because the reservoir was being lowered during the injection and remained low until after the cement grouting. Long strings of asphalt, ejected from holes during the asphalt grouting and subsequent cement grouting, indicated that the asphalt residue was plastic rather than hard.

Present leakage into the drainage tunnel with a full reservoir is 37 gpm as compared with 429 gpm prior to grouting.

C-122 "Pavement Rehabilitation - Materials and Techniques," Synthesis of Highway Practice, No. 9, 1972, National Cooperative Highway Research Program.

Maintenance of damaged pavements would be greatly helped by development of patching materials for portland cement concrete allowing rapid application, minimum equipment in areas of heavy and high-speed traffic. Need also noted for materials for overlays on portland cement concrete pavements that minimize reflection cracking over joints and cracks.

1973

C-123 Derrington, C. F., "Waterproof Membrane Systems for Use on Concrete Bridge Decks," Miscellaneous Paper C-73-2, Jan 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

A literature search showed that several materials have been proposed for use as coatings for concrete. Some of these coatings may be suitable as effective waterproof systems for use on concrete bridge decks. Systems that appear to be most effective as permanent coatings for concrete are primarily of the thermosetting type and include alkyd resins, epoxy-ester, silicone-alkyd, neoprenes, urethanes, polyesters, and epoxy resins. In all of these systems, adhesion of the system to the concrete is of paramount importance, and often adhesion is dependent on the temperature to which the structure is subjected.

C-124 Syamala, R., "Use of Epoxy Resins for Protection of Concrete Surfaces Against Cavitation Damage," Indian Concrete Journal (Bombay), Vol 47, No. 3, Mar 1973, p 113.

The paper presents a review of the current state-of-the-art, and problems associated with the protection of concrete surfaces of high head hydraulic structures with the epoxy resins against the cavitation damage, and the results of some investigations initiated at the Indian Institute of Science investigating the epoxy resins.

C-125 "Epoxy Protective Coatings for Concrete Reinforcement," American Highway, Vol 52, No. 3, Jul 1973, p 5.

Research efforts funded by the Federal Highway Administration (FHWA) have identified four epoxy coatings having the necessary qualities for protecting steel reinforcing bars in concrete decks of bridges from corrosion. Coatings were evaluated on the basis of their chemical and physical durabilities, film integrity, corrosion resistance, and structural soundness.

C-126 MacDonald, M. D., "Concrete Bridge Deck Waterproofing Systems," Highways and Road Construction (London), Vol 41, No. 1764, Aug 1973, pp 26-30.

The function of waterproofing membranes, possibly only 3 mm thick, is to prevent the premature deterioration of the bridge structure. Research into systems and techniques undertaken at the Transport and Road Research Laboratory has enabled the requirements for an effective waterproofing system to be defined. For a membrane to meet these requirements, it must be impermeable, economical in cost, easy to lay on site, and sufficiently robust to withstand conditions likely to prevail during the construction phase. The membrane must be able to tolerate the laying temperatures imposed by such materials as hot bitumen and hot asphalt surfacing and must not produce an unstable layer likely to promote a surfacing failure when subjected to traffic stresses. Also, materials must not fracture if cracks in the deck develop for reasons such as shrinkage, thermal movement, or dynamic loading.

C-127 Akihama, S., Morita, H., Watanabe, S., and Chida, H., "Improvement of Mechanical Properties of Concrete Through the Addition of Polymer Latex," Polymers in Concrete, SP-40, pp 319-338, 1973, American Concrete Institute.

It was found that the strain at maximum compressive and tensile stress of polymer-modified concrete became steadily greater with the increasing polymer content. Compressive strain was measured to be 140, 170, and 320 percent of plain

concrete and tensile strain to be 170, 210, and 300 percent when polymer/cement ratio was 10, 20, and 30 percent, respectively. Toughness was measured to be 146, 182, and 205 percent of plain concrete when polymer/cement ratio was 15, 25, and 30 percent, respectively.

The polymer latex was added during mixing. The specimens were a 10 by 20 cm cylinder, and cured in air at 20° C for 28 days.

Experiments were carried out with shear walls made of the polymer-modified concrete in order to examine the improvement of ductility and toughness under the shear force. The wall specimens were panels of 132 by 193 by 3.7 cm. It was found from the experiments that ductility increased by 160 to 180 percent and toughness increased by 140 to 200 percent of the corresponding values for the ordinary concrete shear wall.

C-128 Canovas, M. F., "Behavior of Epoxy Mortar Coating Under Changes of Temperature," Research Working Paper No. 28, 1973, Instituto Eduardo Torroja de la Contruccion y del Cemento, Madrid.

Epoxy coatings for industrial floors are being applied more each day, due to their resistance to both abrasion and chemicals such as oils, fats, acids, and so on. The techniques for preparing floors for these toppings are varied; the most widely used system consists of using an epoxy mortar coating, in which the aggregate is sand with carefully studied gradation and the binder is a suitable epoxy resin. The mortar formed adheres completely to the concrete base, protecting it and creating flooring with exceptional properties.

However, due to the thermal expansion coefficients of the concrete base on which the application is made and of the layer of epoxy mortar applied to it, stresses appear. It must be determined whether these stresses are within admissible limits or whether they would lead to cracking of the concrete or the layer of mortar. It must also be determined that these stresses will not separate the layer of epoxy mortar from the concrete base.

The present study analyzes the mechanical changes which take place in a coating of this type, and determines whether the stresses which appear when a change in temperature occurs are within admissible limits or whether the coating will separate. The report is in both English and Spanish.

C-129 DePuy, G. W., Kukacka, L. E., "Concrete-Polymer Materials (Fifth Topical Report)," Brookhaven National Laboratory 50390 (TID-4500) and REC-ERC-73-12, 1973, U. S. Atomic Energy Commission, Washington, D. C.

The development program for concrete-polymer materials covers three distinct types of materials: polymer-impregnated concrete (PIC), polymer-concrete (PC), and polymer-cement concrete (PCC). This report covers work performed from 1 July 1971 to 30 June 1972.

C-130 Fowler, D. W., Houston, J. T., and Paul, D. R., "Polymer-Impregnated Concrete for Highway Applications," Research Report No. 114-1, 1973, Center for Highway Research, University of Texas at Austin.

Polymer-impregnated surface treatments have been developed to improve durability of bridge decks. Several monomer systems have been identified that, after soaking into concrete, can be polymerized at temperatures of 125° F or higher. The strength and stiffness of the polymer-impregnated concrete are increased by several times. Evaluations of the surface treatments were performed to determine their effectiveness. After undergoing freeze-thaw tests, many impregnated slabs maintained a relatively water-tight concrete surface. In wear-track tests, eight of nine polymer treatments provided significantly higher skid resistance than control slabs. Surface wear was about equal for treated and untreated slabs. Tests on surface-treated reinforced beams indicated a 22 percent higher strength than for untreated beams.

C-131 Lorman, W. R., "Rapid-Hardening Concrete for Repairing Navy Concrete Structures in Any Geographic Region," Technical Note N-1300, 1973, Naval Civil Engineering Laboratory.

Concrete mixtures, consisting of common aggregate, high-early-strength portland cement, accelerators (either generic or proprietary), and seawater were investigated in the laboratory to determine their compressive strength and also their strength of bond to old concrete. The various constituents

were stored in the atmosphere at 33°, 63°, and 93° F, and the concretes were mixed in the atmosphere at these temperatures. The cylindrical test specimens were cured and tested at these temperatures in the atmosphere and in seawater pressurized to simulate a hydrostatic head of 60 feet. Strength tests were made at ages one hour, four hours, twenty-four hours, and seven days. Correlation of the strength data with logistic factors showed that rapid-hardening concretes, having adequate compressive and bond strengths and costing less than similar concretes incorporating proprietary accelerators, can be produced by using either calcium chloride (4.0% for low slump concrete and 6.5% for high slump) or calcium nitrate (6.5% for either low or high slump).

The recommended concrete mixtures, intended for placement either in the atmosphere or in harbor waters at any depth to 60 feet, may be used by Seabees in restoring damaged or deteriorated Navy concrete structures situated either ashore or underwater in any geographic region.

<u>1974</u>

C-132 Hoff, G. C., "Research and Development of Fiber-Reinforced Concrete in North America," Miscellaneous Paper C-74-3, Feb 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Fiber-reinforced concrete (FRC) in North America is emerging from the laboratory and is finding many potential applications. Steel, mortars, and concretes are being made to improve the characteristics of these concretes, particularly the flexural and impact strengths. Steel-FRC is being used mostly for pavement overlays. Glass-fiber-reinforced cements are being used in architectural products. Plastic-fiber-reinforced products are being used for improved spall and impact resistance. The applications of FRC are limited only by the ingenuity of the user.

C-133 "New Concrete to Speed Pavement and Deck Patching," Public Works, Feb 1974, p 98.

A new fast-setting concrete, which has been field tested by the Division of Highways, is said to set in less than ten minutes and achieve 40 percent of ultimate strength (7500 psi at 28 days) in two hours. Additionally, the concrete bonds readily to existing concrete without saw cutting or taper interlock. It is intended for use in highway and bridge repairs where early reopening is important.

C-134 Dutruel, F. "Concrete Impregnation Techniques," Precast Concrete (London), Vol 5, No. 4, Apr 1974, pp 197-200.

Considers the methods and merits of polymer impregnating of precast concrete. According to the extent of impregnation, i.e., the ratio of the volume of pores filled with resin to the total volume of pores, techniques are evolved. Techniques are described for attaining total, partial, and superficial impregnation.

C-135 Beckett, R. E., "Fibrous Concrete Bridge Decks," Civil Engineering (London), No. 814, May 1974, pp 32-35.

The majority of new road or road improvement projects will involve the construction of both an over and under bridge. Increasing need for economic consideration has led to alternate forms of construction being considered; fibrous concrete has many advantages.

Fiber-reinforced concrete can be applied to a variety of situations within bridge construction: permanent soffit formwork as precast lightweight panels; as total depth construction; as a wearing surface; as a composite construction combined with conventional reinforcement; in expansion joint nosings and curb endings; and shotcrete repairs to existing structures.

C-136 Grenley, D. and Kuhlmann, L., "Chemical Resistant Resurfacing Mortar," Journal, Construction Division, Proceedings, American Society

of Civil Engineers, Vol 100, No. CO2, Jun 1974, pp 133-140.

Historically, concrete and mortar have been used as a flooring and wearing surface because of their availability, durability, and relatively low cost. Under extreme exposure conditions, however, conventional portland cement mortar and concrete are not sufficient. For example, chemicals, abrasion, and freeze-thaw cycling require that some method of protection be given to the concrete, or that another material be used. The most versatile and economical method of protection is a topping of Portland cement mortar modified with saran polymer. The unique chemistry of the saran polymer is such that the mortar bonds tenaciously to the concrete substrate while maintaining superior chemical and abrasion resistance to most environments encountered in chemical and processing plants. Chemical exposure tests, as well as 10 years of history, have demonstrated the performance of this modified mortar.

C-137 Meyer, A. H., "Polymer as Surface Treatment for Concrete," Journal, Structural Division, Proceedings, American Society of Civil Engineers, Vol 100, No. ST6, Jun 1974, pp 1205-1210.

It was determined in this research that a Portland cement concrete surface could be treated with methyl-methacrylate in monomer form and then polymerized in situ by natural sunlight. The penetration of the methyl-methacrylate was 0.4 in. nominally with about 50 percent of the initial loading being polymerized in the concrete surface. The following conclusions were made: (1) It is feasible to use methyl-methacrylate as a surface treatment for Portland cement concrete; (2) such treatment will not significantly increase the strength characteristics of the concrete; (3) such treatment will significantly reduce the amount of water absorbed through the surface of the concrete; (4) such treatment will improve the durability of the surface; and (5) such treatment will reduce the skid-resistance of the surface.

C-138 Steenson, H. N., "Fast Set Shotcrete in Concrete Construction," Proceedings, American Concrete Institute, Journal, Vol 71, No. 6, Jun 1974, pp 289-295.

Shotcrete as a supporting material for tunnels and for tunnel lining has not been used a great deal in North America. This paper discusses the technique of coarse aggregate shotcreting and how it is being used today.

In the past shotcreting was used on a limited basis, mainly as a rock-sealant technique. With advances in technology and equipment, an increased use of coarse aggregate shotcrete in tunnels and underground mines is expected. The main thrust is coming from the ability to use accelerators in wet-mix shotcrete.

C-139 "Deicing Chemicals Avoid Bridge Deterioration," Better Roads, Vol 44, No. 7, Jul 1974, pp 23-25.

The California Department of Transportation, after an exhaustive two-year investigation including both field and laboratory tests, found TKPP (tetrapotassium pyrophosphate) exhibited good frost prevention properties. Due to the relative high cost of TKPP, its use only on bridge decks to inhibit formation of frost was recommended. The most effective use of any tested deicing chemical was to apply it in liquid form prior to the conditions of frost and snow. However, once the snow became packed, crystals of deicer were needed to penetrate and break up the physical structure of the ice or snow. Skid and PCC concrete durability tests were performed.

C-140 Sather, W. R., "Fibrous Concrete Field Batching Sequences," Proceedings, American Concrete Institute, Journal, Vol 74, No. 10, Oct 1974, pp 504-505.

This paper presents mixtures and procedures for four different jobs using steel fibers that were successful applications of fiber reinforced concrete. Paper describes mixing procedures, fiber volumes, aspect ratios, mixing sequences, and material properties.

C-141 Best, C. H., Crary, J. F., Gast, L. E., and Kubie, W. L., "Linseed Oil Formulations as Curing and Antiscaling Compounds for Concrete," Transportation Research Record, No. 504, pp 63-70, 1974, Transportation Research Board.

An extensive testing program was undertaken to determine the effectiveness of linseed oil in mineral spirits both as a curing compound and as an antiscaling compound for inadequately air-entrained portland cement concrete. The testing program is discussed in light of the immediate and residual effectiveness and the value of such linseed oil formulation treatments.

C-142 Chen, W. F. and Mehta, H. C., "Structural Use of Sulfur for Impregnation of Building Materials," Laboratory Report No. 390.9, 1974, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.

The impregnation of building materials such as blocks and bricks with melted elemental sulfur increases the compressive strength by a factor of 2 and modulus of elasticity by a factor of 3. The permeability of sulfur impregnated materials to water and salt solutions is also greatly reduced. Due to the large surplus of sulfur and the low price, sulfur impregnation of building materials will find extensive use in tall building construction.

C-143 Jenkins, J. C., Beecroft, G. W. and Quinn, W. J., "Polymer Concrete Overlay Test Program," Report No. FHWA-RD-75-501, 1974, Oregon State Highway Division.

Describes work done on various combinations of monomers and polymer concrete mixes and identifies the mixes showing the greatest potential for use in bridge deck overlays. Presented are test results showing physical properties of various polymer concrete mixes, such as compressive strength, split tensile strength, modulus of elasticity, thermal coefficient of expansion, and shrinkage coefficient. The effects of polymer content, work time, and temperature on various properties are also discussed. The development of two polymer concrete systems with excellent membrane potential is described along with the details of bonding characteristics of several systems. A polymer concrete mix with suitable properties for deck and pavement patching is detailed.

C-144 Lankard, D. R. and Walker, A. J., "Pavement and Bridge Deck Overlays with Steel Fibrous Concrete," Fiber Reinforced Concrete, SP-44, pp 375-392, 1974, American Concrete Institute, Detroit.

Field experiments designed to evaluate the suitability and effectiveness of steel fibrous concrete as an overlay material for bridge decks, highway pavements, and airfield pavements have been carried out and others are planned. Steel fibrous concrete overlays two to twelve in. thick have been constructed in several states. A three-mile overlay of a county highway was recently completed. Variables which have been investigated include concrete mix design, fiber type and quantity, joint spacing and design, overlay thickness, and the type of bonding to the old surface. Although it will require many years before a complete assessment can be made of the performance of the experimental fibrous concrete overlays, the initial experiences and results have been encouraging.

C-145 Macdonald, M. D., "Waterproofing Concrete Bridge Decks: Materials and Methods," Report No. 636, 1974, Transportation Road Research Laboratory (GB)TRRL.

The requirements for waterproofing materials have been studied, both in the Laboratory and on bridge sites against requirements for adhesion, stability and thermal properties. Laboratory experiments to evaluate the resistance of the membrane system to substrate cracking and damage, by constructural work, at -10°C and 20°C have been developed and standards of performance proposed. The problems of protection of the membrane against damage and blistering are considered.

1975

C-146 Kukacka, L. E., Mediatore, R., Fontana, J., Steinberg, M., and Levine, A., "The Use of Polymer-Concrete for Bridge Deck Repairs on the Major Deegan Expressway," Implementation package, Jan 1975, Federal Highway Administration, Department of Transportation.

Field testing of polymer concretes (PC's) containing polyester-styrene and mixtures of methyl methacrylate (MMA) and trimethylolpropane trimethacrylate (TMPTMA) has been in progress for ~3-1/2 yr and to date no detrimental effects have been noted. The most severe test performed to date was on the Third and Lincoln Avenues Viaduct of the Major Deegan Expressway in the lower Bronx, New York City. This test, performed in December 1973, consisted of filling a 3- by 10- by 1.25-ft hole through the bridge deck with a PC containing a 13 percent concentration of a 95 wt % MMA - 5 wt % TMPTMA mixture. Polymerization was completed within one hour and traffic was restored two hours after completion of the pour. To date, after ~14 months in service, no deterioration is apparent. Cores taken from the section after 10 months in service had a compressive strength of 8670 psi and a boiling water absorption of 1.1 percent, and good bonding to the adjacent concrete was evident.

C-147 Lankard, D. R. and Walker, A. J., "Pavement Applications for Steel Fibrous Concrete," Journal, Transportation Engineering, Proceedings, American Society of Civil Engineers, Vol 101, No. TE1, Feb 1975, pp 137-153.

A number of significant field experiments have been carried out to evaluate the suitability of steel fibrous concrete as an overlay for bridges and pavements, and to study such variables as concrete mix design, fiber type and quality, joint spacing and design, overlay thickness, and the type of bonding to the old surface. Some general observations and comments are relevant: (1) Steel fibrous concrete overlays can be prepared using existing mixing and placing equipment; (2) steel fibers are available for experimental evaluation in reasonably large quantities in the United States; (3) steel fibrous concrete overlays as thin as two inches may be suitable in some applications; (4) there are reasons for expecting satisfactory performance from fibrous concrete overlays containing relatively low quantities of fibers; (5) mix and overlay design changes have helped eliminate premature cracking (nonlive load) of the overlays; (6) the use of shrinkage compensating cements and debonding techniques offers the potential of significant increases in joint spacing.

C-148 Mehta, H. C. and Vanderhoff, J. W., "Polymer-Impregnated Concrete; Field Studies," Journal, Transportation Engineering, Proceedings, American Society of Civil Engineers, Vol 101, No. TE1, Feb 1975, pp 1-27.

The principles developed in the laboratory for polymer impregnation of concrete to depths below the top layer of steel reinforcing rods were applied to the impregnation of large concrete slabs and a bridge deck. The concrete slabs and bridge deck were dried thoroughly using a propane torch assembly (temperature at surface 700°F or 372°C, at a 4-inch (100-mm) depth 250°F or 121°C), impregnated with a 16-inch (410-mm) ethylene film, and polymerized for a 16-inch (410-mm) pressure impregnator at 15 psi-80 psi ($104kN/m^2$-$552kN/m^2$), wrapped or covered with a polyethlene film, and polymerized for five to eight hours using steam from a pressure cooker. The monomer was a 90:10 methyl methacrylate-trimethylolpropane trimethacrylate mixture containing 0.5 percent azobisisobutyronitrile intiator. The slabs were impregnated to their full 6-inch (150-mm) thickness, the bridge deck to a depth of at least 5 inches (125 mm). The polymer-impregnated slabs show increased compressive and split-tensile strengths, decreased water absorption, and improved resistance to corrosion, freeze-thaw cycling, abrasion, and acid-etching. The polymer-impregnated bridge deck shows decreased water absorption and improved resistance to acid-etching.

C-149 "Concrete Patched Fast in Cold Weather," Engineering News-Record, Mar 20, 1975, p 112.

A high-early-strength, fast-setting concrete patching material developed by Republic Steel Corp. was placed pneumatically at 31°F with a wind of about 15 mph to repair an overpass at Warrensville Heights, Ohio.

According to Republic, its material (dry aggregate with powdered magnesia and an activator solution) sets in seven minutes and a roadway can be reopened to traffic within two hours.

C-150 Sommer, H., "Wear-Resistance of Resin-Bound Mortar to Studded Tyres," Proceedings, First International Congress on Polymer Concretes, England, 5-7 May 1975, pp 323-326.

This paper discusses the wearing resistance of various polymer mortars used as surface treatments to roadways. The program utilizes a special machine to simulate the traffic wear of studded tyres on the polymer mortar overlays.

C-151 "Stop Deterioration of Bridge Decks," American City, Vol 90, No. 5, Buttenheim Publishing Corporation, May 1975, p 36.

A recently developed process for inserting small wax beads into concrete during the mixing stage appears to offer a relatively inexpensive and effective solution to the bridge deck deterioration problem. After the concrete has been placed and hardened, the wax is melted by mildly heating the concrete slab so the wax flows into the capillaries and pores of the concrete. Upon cooling, the wax solidifies and plugs the capillaries and pores.

C-152 "Compound Tested as Concrete Sealant," Public Works, Vol 106, No. 7, Jul 1975, pp 63-65.

As a means of slowing salt damage to existing bridge decks, a one-time application of a penetrant solution, long used on concrete as a sealant but not on roadways, has been suggested. Partial protection thus obtained could provide time for implementing more thorough construction measures such as sprayed-on polyvinyl chloride membrane; heavy concrete; precast membrane; resurfacing with latex mortars; polymer impregnation; use of epoxy-coated reinforcing bars; the addition of tiny wax globules in new concrete which, after application of heat, melt to fill the capillaries; sulfur impregnation; densifying with pozzolan; installing cathodic protective systems; or other methods.

C-153 Dickerson, R. F., "Progress Report on Concrete Reinforced with Steel Fibers," Concrete Construction, Vol 20, No. 7, Jul 1975, pp 281-283.

Interest in fiber reinforced concrete has been high since articles on the material began appearing in the early 1970's.

Since then, research has been done and construction practices developed. This article briefly reviews what has been learned about handling the material, its use on bridge decks, highways, and runways, shotcrete applications, and other slab-on-grade applications.

C-154 Henager, C. H., "A New Wrinkle-Shotcrete Containing Steel Fibers," Concrete Construction, Vol 20, No. 8, Aug 1975, pp 345-347.

Shotcrete has normally been a mortar or concrete conveyed through a hose or pneumatically projected onto a surface at high velocity. A new development has been to include steel fibers in the mix. Fiber sizes used to date have ranged from 1/2- to 1-1/2-inch-length and from 0.010- to 0.016-inch-diameter. They have generally been applied by the dry shotcrete process in which the dry mixture is pumped through a hose and water added at the nozzle.

Material and shotcrete properties, mix proportioning, mixing and placing, and applications of steel fiber shotcrete are discussed.

C-155 Clark, E. J., Campbell, P. G. and Frohnsdorff, G., "Waterproofing Materials for Masonry," National Bureau of Standards Technical Note 883, 1975, National Bureau of Standards.

The initial effectiveness and durability characteristics of 55 clear masonry waterproofing materials were evaluated using laboratory tests. This report contains the results of initial performance tests including water absorption, water vapor transmission, resistance to efflorescence, and change in appearance. Durability tests, including periodic measurement of water absorption after exposure to accelerated weathering and outdoor exposures, were also conducted. Based on test results, performance criteria for clear waterproofing materials were developed. In addition, the report contains a summary of a survey concerning field experiences with waterproofing and a brief theoretical discussion of water flow.

C-156 DePuy, G. W., "Highway Applications of Concrete Polymer Materials," Transportation Research Record, No. 542, pp 60-66, 1975, Transportation Research Board.

The deterioration of concrete bridge decks and pavements presents many highway organizations with major problems of providing safe and satisfactory riding surfaces. Concrete polymer materials, with their excellent durability and strength properties, have potential application to highway construction and maintenance and offer potential benefits of an increase in service life and a reduction in the costs, safety hazards, and inconveniences in performing maintenance and repair work. Polymer-impregnated concrete is highly resistant to freeze-thaw damage and water penetration and provides protection from deicing salt penetration and corrosion of reinforcing steel. A precast, prestressed polymer-impregnated concrete bridge deck system is being developed that incorporates the advantages of a precast, prestressed system for rapid construction and strength; and a surface-impregnation technique is being developed for field treatment of newly constructed concrete bridge decks to provide protection of reinforcing steel from deicing salts. Polymer concrete is a versatile new material with properties comparable to polymer-impregnated concrete and appears to be suitable for both precast and field applications, such as curbstones, pavements overlays, shotcrete, and rapid-curing patching and repair materials.

C-157 Dutruel, F., "Partial Impregnation of Concrete with Polymerizable Resins," Proceedings, 8th International Congress of the Precast Concrete Industry, BIBM (Stresa, 12-19 May 1975) and Cement and Concrete Association, London, 1975.

This summary study mainly aims to show that only the superficial impregnation technique is both possible and capable by itself of solving the various problems existent in the precast concrete manufacturing industry.

This technique is extremely simple and can be summarized as a curing followed by an immersion and then a polymerization. All operations can be carried out in the same area used for the curing.

The analysis of some mechanical and physical-chemical properties show aspects of this technology which has been

experimented with by the Centre d'Etudes et Recherches de L'Industrie du Béton Manufacturé (CERIB).

Today a pilot unit, as intermediary between the laboratory and the industry has the opportunity of both verifying the data obtained in the laboratory and evaluating the operating costs of impregnation.

C-158 Fowler, D. W. and Paul, D. R., "Partial Polymer Impregnation of Highway Bridge Decks," Transportation Research Record, No. 542, pp 9-19, 1975, Transportation Research Board.

Polymer-impregnated concrete is being considered as a means of increasing the durability of bridge decks. For application to existing bridges, the process includes drying the bridge deck to remove the free moisture in the pores, soaking a low viscosity monomer solution into the concrete, and applying heat to polymerize the monomer. Drying, soaking, and curing requirements are discussed.

A limited area of a bridge deck has been successfully polymerized to a depth of approximately 1 inch (2.5 cm). Evaluation studies were conducted to determine the freeze-thaw resistance, skid and wear resistance, and protection against corrosion of the reinforcement in relation to polymer-impregnated concrete. Freeze-thaw resistance was significantly increased, and skid resistance improved significantly for the partially impregnated slabs when the tests were performed when the surfaces were dry. Skid resistance was slightly higher when the surfaces were covered with abrasive grit and kept wet. Wear measurements generally indicated little difference between treated and untreated specimens. Corrosion resistance for slabs with a low-quality polymer impregnation is about 25 times greater than that for unimpregnated slabs.

C-159 Mahar, J. W., Parker, H. W. and Wuellner, W. W., "Shotcrete Practice in Underground Construction," Report No. FRA-OR&D 75-90, 1975, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Ill.

This report describes the use and procedures for placement of wet- and dry-mix shotcrete in underground rock

excavations. Its purpose is to serve as a guide for designers and contractors in selecting, preparing, and applying shotcrete of acceptable quality in the variety of ground conditions encountered in underground work. The contents of this report include design considerations, engineering properties, shotcrete equipment, application techniques, and quality control. Specifications for shotcrete are treated as well. The appendixes provide supplemental information dealing with the use and engineering properties of fiber and regulated-set cement shotcrete, capabilities and specifications of shotcrete machines, and some recommended guidelines for placing shotcrete underground.

C-160 Newlon, H., Jr., "Evaluation of Several Types of Curing and Protective Materials; Part IV, Final Report on Performance," Report No. VHTRC 76-R5, 1975, Virginia Highway and Transporation Research Council, Charlottesville, Va.

Various curing and/or protective coatings were evaluated under three conditions: (1) accelerated laboratory freezing and thawing of specimens in two percent sodium chloride solutions, (2) exposure in an outdoor area of slabs subjected to controlled application of deicers, and (3) exposure of some of the materials on three interstate bridges for five winters.

It is concluded that: (1) properly entrained air is overwhelmingly the most effective defense against scaling; (2) when insufficient entrained air is obtained, linseed oil treatments delay the onset of scaling but do not prevent it; (3) materials intended to cure and protect in a single application are not effective; and (4) linseed oil treatments applied after curing with membrane curing are effective without prior removal of the curing compound.

C-161 Potter, W. G., Uses of Epoxy Resins, Chemical Publishing Co., Inc., New York, 1975.

A comprehensive treatment of the techno-economic background to the use of epoxy resins. The book reviews the wide range of uses of epoxy resins, and in most instances shows why epoxy resins were chosen rather than other materials. In some instances new uses for the resins will be

discovered by those who know them well, and others will be encouraged to experiment with epoxy resins where they have not used them before.

The contents include: surface coatings; electrical and electronic insulation; construction industry applications; and other principal applications.

C-162 Thornton, J. B., "Rigid Pavement Joints and Sealants Study," Report No. 6903, 1975, Office of Materials and Research, Georgia Department of Transportation, Atlanta, Ga.

This publication is a final report on a study initiated to evaluate the relative performance of a number of different types of rigid pavement joint sealants. The project has been designed to provide information on the effect that several joint variables might have on the performance of the joint sealant design. These design variables include joint spacing and orientation (skewed or square) as well as sealant design properties. The report describes the equipment and procedures used in establishing the test locations and obtaining performance data.

The report contains a detailed discussion on each type of sealant used as well as installation procedures and problems. In addition, cost estimates for each type of sealant and installation were furnished by the contractor and are tabulated in the report.

1976

C-163 Isherwood, C., "Tapecrete: A New King of Surfacing Material," Engineering Journal/Revue de L'Ingenierie (Montreal), Vol 59, No. 1, Jan 1976, pp 68-69.

Describes a new product available in Canada which may solve some of the sealing problems in the construction industry. The product has a variety of uses from surfacing and repair of highway bridges to lining nuclear storage structures. The product is made of cement, polymers, and chemical additives mixed into a slurry. The other component is a fabric (specially treated glass or steel) which is impregnated with the slurry and placed on the surface. Costs and other properties are compared with competitive products, such as wearing and nonwearing membranes and epoxies.

C-164 "Dam Fights Erosion with Plastic Coat of Armor," Engineering News-Record, Vol 196, No. 11, Mar 11, 1976, pp 18-19.

Polymer-impregnated concrete now lines an outlet tunnel and part of the stilling basin floor at Dworshak Dam in Idaho, providing protection against erosion and cavitation experienced during the first few years of operating the 717-ft-high gravity structure. Its voids plugged with plastic, the concrete has a compressive strength four to five times that of untreated concrete.

The first large-scale polymerization project in the United States took about nine months to complete. Three types of concrete - fiber reinforced, conventional, and dry-pack - on both vertical and horizontal surfaces, in an enclosed area as well as in the open, were polymerized. The type used depended on the severity of the damage.

C-165 "Precast Concrete Fins Stabilized with Pressure Grouted Epoxy," Journal, Prestressed Concrete Institute, Vol 21, No. 3, May-Jun 1976, pp 43-45.

Describes the application of a pressure grouted epoxy adhesive to stabilize the projecting precast concrete fins of a multilevel parking garage in San Francisco, Calif. Altogether, there were ten fins, 23 ft 7 in. long, 3 ft wide, and 8 in. thick.

C-166 Mattison, E. N., "Epoxy Resin Repair of Cracked Concrete: A New Method," Rebuild, Division of Building Research, Commonwealth Scientific and Industrial Research Organization, Vol 1, No. 4, Aug 1976, p 34.

Over the past two decades epoxy resin has found increasing application in the repair of cracks in concrete. The adhesion of resin to concrete and its relatively high tensile strength enables structural and watertight repairs to be effected. Cracks are filled with epoxy resin at the present time by one of three methods: penetration by gravity, use of the natural capillary forces, or positive injection using high or low pressure. All of these methods tend to deface the concrete surface, often requiring additional treatment such as painting.

This article introduces a new technique for filling cracks: the use of suction, whereby the air pressure in the crack is lowered by a vacuum pad. Resin introduced to the crack at the surface of the concrete is then drawn well in and a neater and more effective repair results. Equipment, techniques, and the results of laboratory and field tests are described.

C-167 "Polymer Concrete Composites," Journal, Concrete Society of Southern Africa, Johannesburg, South Africa, No. 3, Sep 1976, pp 3-4.

Polymer, monomer, and polymerization are defined while the processes of polymer impregnated concrete and polymer cement concrete are explained with examples of their use in concrete.

C-168 Pomeroy, C. D., "Commercial Prospects for Fiber and Polymer-Modified Concretes," Precast Concrete (London), Vol 7, No. 10, Oct 1976, pp 522-523.

An appraisal was made of the benefits that accrue from fibers and polymers in concrete in an attempt to establish areas in which their incorporation is likely to be commercially worthwhile. This paper is based on the appraisal. The two classes of material are introduced separately, and their individual characteristics are discussed. A general discussion of their commercial application follows.

C-169 Brekke, T. L., Einstein, H. H. and Mason, R. E., "State-of-the-Art Review on Shotcrete," Contract Report S-76-4, 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Contains the results of four studies pertaining to shotcrete technology. The first part of the report is an overview of American practices in shotcrete. The second part is a discussion of the development and practice of shotcrete technology in Europe, including a description of the New Austrian Tunneling Method (NATM). The third part describes

the experiences of the U. S. Bureau of Reclamation in using shotcrete for tunnel linings and their design and construction concepts. The final part of the report is a discussion of instrumentation currently employed for obtaining the data used in design of shotcreted tunnels being constructed by the NATM. The NATM involves the use of the theoretical-observational approach to design. Each part of the report also gives recommendations as to needed research requirements and suggestions pertaining to possible extended uses of shotcrete in this country.

C-170 Clifton, J. J., Fearn, J. E., Anderson, E. D., "Polymer Impregnated Hardened Cement Pastes and Mortars," Building Science Series No. 83, 1976, National Bureau of Standards, U. S. Department of Commerce.

Polymer impregnated hardened cement pastes and mortars have been prepared and their properties compared to those of control specimens. Specimens were made by impregnating dried and evacuated precast hardened cement pastes and mortars with methyl methacrylate, under pressure, which was thermally polymerized. The effects of the microstructure of the cement pastes and mortars on the performance of polymer impregnated mortars were determined by preparing specimens with a wide range of porosities by varying the water-cement ratio and the curing times prior to impregnation.

The properties of impregnated and control specimens were investigated by scanning electron microscopy for porosity determinations. The polymer impregnated materials had compressive and flexural strengths, moduli of elasticity, and fracture toughness which were substantially higher than unimpregnated materials.

C-171 Husbands, T. B. and Pepper, L., "Laboratory and Field Evaluation of Polymeric Cavitation Erosion-Resistant Materials on Concrete," Technical Report C-76-2, 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Fifteen polymeric coatings for protecting concrete against cavitation erosion were evaluated. Eight of these materials were found to be cavitation erosion-resistant. Five of these eight materials were polyurethane sheet materials; the other three were a liquid-applied polyurethane, a neoprene sheet, and a liquid-applied neoprene.

The materials were evaluated by coating mortar specimens with the materials and determining the adhesive bond strength. Those materials which were bonded successfully to the mortar and which showed promise for field application were evaluated further by determining the durability of the bond and the material to water immersion. A nondestructive test method (ultrasonic) was evaluated to determine optimum application of materials in the field.

The laboratory and field applications showed that sheet materials are extremely difficult to apply. It is difficult to obtain buckle-free surfaces and good joints between adjacent sheets, and to coat irregular surfaces. The only liquid-applied material evaluated which showed any promise for protecting concrete against cavitation-erosion damage was the liquid polyurethane material.

The following recommendations were made: (a) additional field trials should be made with the liquid polyurethane; (b) epoxy resins should be used as a protective material when only moderate cavitation exposure is expected; (c) the search for superior cavitation-resistant materials should be continued using the procedures outlined in the report; (d) the search for a nondestructive method for field evaluation of bond should be continued; and (e) the test section should be altered to prevent vibration of the concrete sidewalls and also to permit inspection of the specimen without disturbing the test material.

C-172 Lorman, W. R., "Engineering Properties of Epoxy Resin as a Structural Adhesive for Cracked Concrete Waterfront Facilities," Technical Note, No. N-1429, 1976, Naval Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme.

The assessment of information in the technical literature pertaining to the engineering properties of epoxy resin as an adhesive material for injection under pressure into cracks in Navy reinforced concrete waterfront facilities as a means of restoring structural integrity covers the period from 1950 to 1975. The review reveals that the available engineering data suffice for establishing a practical guide for civil engineers concerned with such application of epoxy resin.

The report condenses a multitude of facts, quantifies the range of values relative to the physical characteristics of hardened epoxy resin, outlines the essentials of approaching a structural bonding problem, and briefly describes the

procedure for consolidating a cracked concrete structural member by pressurized injection of epoxy resin.

The report pertains to crack repairs that are essential for the stability of concrete waterfront structures; it is not intended to deal with sealing cracks and joints either against penetration of foreign matter or to prevent leakage.

C-173 "Polymers in Concrete," Proceedings, First International Congress on Polymer Concretes (London, 5-7 May 1976), The Concrete Society, London, 1976.

Contains papers presented at the First International Congress on Polymer Concretes held in London in May 1975. Contributions from over 60 concrete and plastics specialists involved in the use of polymers in concrete discuss: polymer impregnated concrete, concretes with polymers added, with dispersed polymers, and resin bound aggregates. A good portion of the volume is devoted to papers on practical applications of polymer concrete. The existing worldwide state of affairs of polymers in concrete is also discussed.

C-174 Popovics, S., "Polymer Pavement Concrete for Arizona - Study II," Report No. FHWA-AZ-RD-74-154, 1976, Arizona Department of Transportation, Phoenix, Ariz.

The most important result of this investigation is the development of the addition of urea-formaldehyde combinations in the form of a monomer system to the mixing water of portland cement mortars and concretes. Although the addition of this system to concretes produced only negligible strength increases, experimental data indicated that several combinations of the same system with mortars produced compressive strength increases of 1500 to 2500 psi.

It is not clear at this time why the urea-formaldehyde monomer system is effective in mortars and ineffective in concretes. Further investigation is needed to improve the effectiveness of this monomer system in concretes, too. The application of such a monomer system is also advantageous from economical standpoint because this is the least expensive form of the urea-formaldehyde combinations, and because the technology of such monomer systems in mortars and

concretes is simple, and despite the present ineffectiveness of the urea-formaldehyde monomer system in concretes, it still seems a significant breakthrough that the admixing of an unpolymerized urea-formaldehyde system increases considerably the strength of portland cement mortars.

Several other directions were also investigated such as the optimization of the basic urea-formaldehyde prepolymers, acidic urea-formaldehyde prepolymers, and several other chemical systems and commercially available polymers. Some of these systems did produce strength increases but these were insignificant.

1977

C-175 Rivard, G. A., "Concrete Floor Coating," Concrete Construction, Vol 22, No. 1, Jan 1977, pp 25-27.

The right concrete floor coating, correctly applied, can change a perpetual source of problems into a smooth, trouble-free "highway" for all foot and wheeled traffic in a building. Yet all too often adequate surface protection and maintenance follow only after floor problems become a major expense.

It is easier and less expensive to build a properly protected surface during the original construction. But even old, eroded floors can be brought back to acceptable standards with currently available materials and methods. This article describes hardening agents, sealer, and finishes for new constructed floors, and toppings for floors that have started to erode.

C-176 Kukacka, L. E. and Fontana, J., "Polymer Concrete Patching Materials Users Manual," Implementation Package 77-11, Volume 1, Apr 1977, Federal Highway Administration, Department of Transportation.

This manual outlines the procedures for using polymer concrete as a rapid patching material to repair deteriorated concrete.

The process technology, materials, equipment, and safety provisions used in the technique are discussed. The objective of the report is to inform potential users of the various steps necessary to insure successful field application of the material.

The manual lists as advantages of polymer concrete: Rapid curing - less than two hours, high strength - in excess of 500 psi, good bond to existing concrete.

C-177 Chung, H. W. and Liu, L. M., "Epoxy-Repaired Concrete Joints," Proceedings, American Concrete Institute, Journal, Vol 74, No. 6, Jun 1977, pp 264-267.

Shear tests were carried out on concrete pushoff specimens which were severely damaged and then repaired by epoxy injection. The test results illustrate the effectiveness of the repair process.

Undated

C-178 "Effect of Various Substances on Concrete, and Protective Treatments, Where Required," Concrete Information Bulletin ST-4-2, Portland Cement Association, Chicago, Ill.

Concrete of a suitable quality must be assumed in a discussion of the effect of various substances on concrete, and protective treatments. In general, this means a properly proportioned, carefully placed and well-cured concrete resulting in a watertight structure. In structures which are to be subject to frequent wetting and drying, it is essential to provide impervious concrete and sufficient coverage over the steel, and it may be advisable to provide some surface coating such as sodium silicate, linseed oil or one of the varnishes as an added precaution. The best material to use in a case will depend on many factors in addition to the substance to be protected.

C-179 Williamson, A. S., "Epoxy-Urethane Liner for Neutralizing Sumps," Ontario Hydro Research Quarterly, The Research Division, Hydro-Electric Power Commission of Ontario, Vol 25, No. 1, pp 15-21.

Studies of various liquid-applied polymeric liner systems for the protection of concrete neutralizing sumps in thermal generating stations have shown that excellent performance is provided by composites of a sand-filled epoxy

surfacer and urethane elastomer membranes. Traditionally, protection against the corrosive and erosive effects of the liquors contained in these sumps has been attempted by lining the concrete with various other types of coatings, acid-resistant brick, sheet polyvinyl chloride, or sheet rubber liners. The epoxyurethane system has been installed in three operational neutralizing sumps with satisfactory results. A service life of at least 20 years is expected with a minimum of maintenance.

SECTION D

MAINTENANCE AND REPAIR PROCEDURES AND TECHNIQUES

1930

D-1 Ahlers, J. G., "Fire Damage to and Repair of a Concrete Factory Building," Proceedings, American Concrete Institute, Vol 26, May 1930, pp 748-759.

A contractor's engineering report on repairs to a concrete building damaged by an intense concentrated fire. The damage to a section of the one floor necessitated removal of the floor above and the rebuilding of one section of the building. Construction methods used are described.

1933

D-2 Evans, L. T. and Rossen, M., "Earthquake Damage to Masonry Structures and Their Repair," Proceedings, American Concrete Institute Vol 30, Nov-Dec 1933, pp 129-136.

Authors cite some of the lessons learned and show some of the repair methods used on brick and concrete structures damaged by earthquake at Long Beach, Calif. A majority of failures in brick structures were of two types: diagonal fractures that usually followed mortar joints, and horizontal shear cracks. Most of the damage in reinforced concrete structures was due to poor design or poor construction. Repair methods included the use of shotcrete "welds."

The authors recommend design procedures to eliminate much of the damage resulting from earthquakes.

1934

D-3 Davis, R. E. and Davis, H. E., "Bonding of New Concrete to Old at Horizontal Construction Joints," Proceedings, American Concrete Institute, Vol 30, May-Jun 1934, pp 422-436.

Presents results of tests to determine the relative efficiency of various methods of bonding new concrete to old under conditions similar to those that exist along horizontal construction joints in dams. Authors discuss the effect of several methods of placement and several methods of joint treatment on: permeability along plane of joint, bond strength

[redacted]

as indicated by the flexure test, and quality of concrete as indicated by unit weight and compressive strength. Methods of compaction were hand tamping, internal vibratory tamping, and combined internal and surface vibratory tamping. Methods of surface cleanup were wire-brushing, scouring with air-water jet before final set, cleaning with high-pressure air after final set. In some cases, lifts were deposited directly on the surface of the previous lift; in other cases, a layer of mortar was flushed on the old surface first. The following variables were included: richness of mix, type of cement, consistency of concrete, period of exposure of lower lift to drying in warm air, time interval between lifts, and age of concrete at test.

1936

D-4 Capp, F. W., "Maintaining Concrete Structures," Proceedings, American Concrete Institute, Vol 32, May-Jun 1936, pp 579-592.

Deterioration of concrete structures due to (1) occluded water plus low temperature, (2) corrosion of reinforcing bars, and (3) unanticipated stresses is considered. The maintenance methods to be followed in dealing with the three causes of deterioration are outlined.

D-5 Harza, L. F. and Roby, H. G., "Concrete Maintenance," Proceedings, American Concrete Institute, Vol 32, May-Jun 1936, pp 571-577.

Points out that maintenance and repairs to concrete structures which are suffering from disintegration of the concrete are often, if not usually, considered as a contracting problem rather than an engineering problem. Suggests that such problems should be carefully studied by engineers to insure that the repair work will prove satisfactory.

The repairs made in 1932 to the spillway of a dam constructed in 1922 are described. The spillway and the gate pier concrete was apparently placed without due care in mixing, stripping, gravel, borrow-pits, placing, etc., and disintegrated badly in 10 years. A new concrete facing about 2 ft 8 in. thick was placed on the downstream side of the spillway and the gate piers were replaced completely. The new spillway facing was reinforced by 1-in. round deformed bars on 12 in.

centers both ways, 6 in. in from the surface. The new facing was anchored by 1 in. round dowels embedded 40 in. into the original structure. Bond between the old and new concrete was obtained by applying a plaster coat of 1:3 mortar on the old concrete. The mortar was thrown against the old concrete and then vigorously slapped by hand to cause the neat cement to penetrate into the old concrete. The repairs have proved satisfactory in all respects.

1937

D-6 Hirschthal, M., "Maintenance and Repair of Concrete Structures in Railroad Construction," Proceedings, American Concrete Institute, Vol 33, Jan-Feb 1937, pp 251-278.

This paper begins by outlining the basis of the selection of concrete as a structural material from the viewpoint of railroad management shortly after the turn of the century - that concrete requires no maintenance; and then makes a comparison of structures built on the D.L.&W. Railroad between that time and 1916, with their condition 20 years later (1936) to evaluate the soundness of such conception. The conclusion from this comparison indicates that, while in this climate, concrete definitely requires protection or maintenance as evidenced by these structures. Twenty-five years of exposure have not undermined their integrity and with but minor expense they have a long life ahead of them.

Traces the causes of deterioation between design and construction: under design, aside from provision against stresses due to loads and soil bearing, the details for drainage, location of expansion and construction joints to compensate for volume and temperature changes; under construction, proportioning of concrete mixtures, selection of materials, workmanship of mixing and placing, and curing. Causes of failures are discussed in the description of the condition of the various structures.

Second section discusses methods of repair, describing four types: (a) patching, (b) coating, (c) encasement, and (d) replacement of a part of, or a whole, member, and specifying the methods of such work.

Summarizes in conclusion the causes of cracks and deterioration, listing these between (a) structural and (b) installation - materials and methods; followed by a list of precautions to be taken when making repairs. An appendix giving "specifications for concrete repair work" is included.

D-7 Reeves, A. B., "Concrete Rehabilitation Work on the Uncompahgre Project," Proceedings, American Concrete Institute, Vol 33, Jan-Feb 1937, pp 303-310.

The South Canal extending from the outlet of Gunnison Tunnel to the Uncompahgre River in western Colorado is one of the principal features of the Uncompahgre Project of the Bureau of Reclamation.

Most of the concrete lined channel had 1/2 to 1 side slopes, 6 in. thick. Approximately one half of the lining was reinforced. This canal was constructed in 1906 and 1907, and specifications for the concrete work were in accordance with standards of that period. This resulted in a permeable and low grade of concrete as compared to present day requirements.

During 30 years of operation a good many failures had occurred due to (1) disintegrating action of alkali, believed to be contributed by the underlying shale material; (2) settlement of foundation; (3) swelling of shale under the lining; (4) hydrostatic pressure under the lining; and (5) weathering, including frost action.

This canal was rehabilitated during the nonirrigation seasons, (November to March) from 1934 to 1937. In places where the old concrete was badly broken up, a new lining of reinforced concrete approximately 6 in. thick was placed inside the old channel, care being taken to secure bond and anchorage to the old lining wherever possible. Modern standards of concrete construction were carried out resulting in compressive strength averaging 550 psi for test cylinders 28 days old. Particular attention was given to finish to secure a low friction coefficient, thus maintaining the capacity.

Where the lining was badly cracked but still in place and held together by the reinforcement, the method of repair was to cover the entire surface with shotcrete. The shotcrete layer is from 0 to 4 in. thick reinforced with bars at 12 in. both ways. Care was exercised to insure a clean surface for the shotcrete, and to secure a bright glazed surface which has a good roughness coefficient.

Bulged floors in the tunnels were repaired by replacement of the old concrete by a new section with a curved invert, thus eliminating the necessity for reinforcement.

D-8 Young, R. B., "Concrete: Its Maintenance and Repair," Proceedings, American Concrete Institute, Vol 33, Mar-Apr 1937, pp 367-393.

Maintenance and repair have much in common and in many cases it is difficult to say whether the remedial work being done is one or the other. In any case, the difference is largely one of degree and the methods are essentially the same. The paper makes no attempt to separate the two, for the principles underlying both maintenance and repair work are the same and similar methods and materials are used.

Author classifies the various methods under the headings of surface treatments, waterproofing, pointing and caulking, patching, surfacing with mortar coatings, and replacement; he then discusses each method in detail and describes some typical repair and maintenance jobs.

1939

D-9 McCullough, C. B., "Maintenance and Repair of Bridges," Proceedings, American Concrete Institute, Vol 35, Feb 1939, pp 229-256.

Maintenance costs for highway bridge structures are affected by a number of factors - original design adequacy, traffic burden, local climatic conditions, and the character of the stream itself all play an important part. Those major items of maintenance expense for timber structures, steel structures, and structures of plain and reinforced concrete are discussed with emphasis on reinforced concrete in areas of low temperature and heavy ice and snow (structures in that portion of Oregon east of the Cascade Range) with many annual cycles of freezing and thawing. Specialized technique for waterproofing handrails, balustrades and other exposed structural portions, and moderate-heat cement are used. Reports average unit costs for those items of expense ordinarily encountered in the maintenance of the various types of highway bridge construction, and treats the effect of design details on bridge maintenance expense and the development of special low-maintenance structural types.

1941

D-10 Davis, R. E., Davis, H. E., and Kelly, J. W., "Weathering Resistance of Concretes Containing Fly Ash Cements," Proceedings, American Concrete Institute, Vol 37, Jan 1941, pp 281-296.

Investigation, extending scope of investigation previously reported was undertaken to determine whether fly ashes of moderately high carbon content could be used advantageously as pozzolanic replacements for small percentages of portland cement, particularly with regard to weathering resistance of concrete. Eleven fly ashes varying in carbon content (1 to 17 percent) and fineness (specific surface 2500 to 5500 sq cm per g) were each admixed with a modified portland cement, with 10 and 20 percent of cement replaced by an equal weight of fly ash. The fly-ash cements thus produced were tested to determine the water requirement, time of setting, autoclave expansion, tensile strength of standard mortar, compressive strength of concrete, drying shrinkage of concrete and resistance of saturated concrete to the action of repeated freezing and thawing. Herein the performance of the fly-ash cements is compared with that of the portland cement, and the influence of carbon content, fineness, and amount of fly ash is shown. On the whole, the use of fly ash resulted in concretes of quality equal or superior to that obtained with the portland cement alone.

1943

D-11 Davis, L., "Repairs to Concrete Structures," Technical Bulletin No. 23, pp 67-71, 1943, West Virginia University Engineering Experiment Station.

Discussion of method of determining cause of disintegration, defects in concrete structures and feasibility of making repairs.

1944

D-12 Carlson, C. C., "Experiments in Repairing and Obscuring Cracks in Concrete Structures," Concrete (London), Vol 52, No. 2, Feb 1944, pp 6-8.

In studies made by Portland Cement Association, as to possibilities of pressure grouting for filling and obscuring cracks, procedure has much in common with other grouting methods; it consists essentially of surface sealing, except at selected intervals where short lengths of crack are left open to provide for injection of cement grout; illustrated description of principal steps in crack repair procedure.

1945

D-13 Paxson, G. S., "Maintenance and Repair of Concrete Bridges on the Oregon Highway System," Proceedings, American Concrete Institute, Journal, Vol 42, Nov 1945, p 105.

Describes types of concrete disintegration and methods and materials used in Oregon for repair and replacement and for protection against further deterioration.

D-14 "Repair of Flood-Damaged California Bridges," Public Works, Vol 76, No. 12, Dec 1945, pp 23 and 42.

Report describes how California State Highway Department repaired two reinforced concrete bridges whose piers had been undermined by flash floods.

1946

D-15 "Dry Packing and Grouting of Substructure Salvages 90-Year-Old Montreal Bridge," Engineering News-Record, Jan 10, 1946, pp 120-122.

Grouting under pressure was successfully used to replace mortar and solidify the masonry of piers built in 1854 for a bridge across the St. Lawrence River. Deteriorated stones in the exterior masonry are replaced by packing with crushed stone and intruding grout, with essential admixtures, into it. Long approach abutments of stone arch construction have been strengthened by forming a new arch underneath the original by dry packing crushed stone against the arch and forcing grout into it to make concrete.

D-16 Boswell, C. C., and Giesecke, A. C., "Maintenance of Heavy Concrete Structures, Minnesota Power and Light Company Practice, Proceedings, American Concrete Institute, Journal, Vol 42, No. 2, Feb 1946, pp 277-288.

The practice of the Minnesota Power and Light Company in repairing and restoring a concrete dam is described and illustrated and comparisons made with a much older structure, which has had no repair cost because construction methods were better.

D-17 Kelly, J. W., and Keatts, B. D., "Two Special Methods of Restoring and Strengthening Masonry Structures," Proceedings, American Concrete Institute, Journal, Vol 17, No. 4, Feb 1946, pp 289-304.

Structures and foundations damaged by weather, erosion, scour or settlement have been restored and strengthened by ingenious methods involving the pumping of cement-base stabilizing material into small interstices and the filling of larger spaces by aggregate which is then embedded in the stabilizing material under pressure. Herein are described several applications of the methods to various structures including bridge piers and abutments, reservoirs, dams, and underwater construction.

D-18 Anderson, A. A., "Maintenance and Repair of Portland Cement Concrete Pavement," Proceedings, American Concrete Institute, Journal, Vol 42, Apr 1946, p 477.

Highway maintenance consists of routine maintenance which is carried on daily and special maintenance conducted at appropriate intervals with specially trained crews - the better the routine maintenance, the less special maintenance is needed.

Routine maintenance operations consist largely of sealing cracks and joints against infiltration of dirt and water and maintaining that seal. Operations vary with types of joints and climatic and subgrade conditions. Maintenance procedure for expansion joints filled with nonextruding and extruding material, contraction joints, and construction joints and cracks is described.

Items of special maintenance are covered in considerable detail as they generally require more engineering supervision.

Patching concrete pavements with concrete is best because, when properly done, patches are integral with the pavement and not inferior to the original slab. Procedure and methods of construction, based on extensive experience records, are discussed under the headings: slab thickness, removal of old slab, preparation of subgrade, materials and proportions of concrete, finishing, and curing.

"Mudjacking" and materials and mixtures for the slurries are outlined as a means of both raising settled slabs and minimizing and preventing damage from pumping slab ends.

Methods and means of protecting existing concrete pavements against surface scale where air-entraining portland cement was not used during construction are also outlined.

D-19 "Repair of Reinforced Concrete Damaged by Fire," Concrete and Construction Engineering, Vol 41, No. 4, Apr 1946, pp 109-111.

Recommendations of methods for repairing reinforced concrete columns and solid concrete and hollow tile floors damaged by fire, including effect of heat on color of concrete.

D-20 Young, R. B., "The Repair of Concrete: An Introduction," Proceedings, American Concrete Institute, Journal, Vol 42, No. 6, Jun 1946.

The repair of concrete structures is an engineering problem, each job containing the elements of diagnosis, treatment, and execution. Diagnosis is essential to devising successful repair. Treatment may mean the correction of faults of design, materials, workmanship; protection against destructive agents and exposure; restoration of decay; or a combination of these. The execution of repair may sometimes use methods of expediency rather than logic - a compromise between what one would like and what one can do. The paper considers the more common agents destructive to concrete and is a brief introduction to an important subject.

D-21 "Cantilevered I-Beams Support Forms for Concrete Bridge Walk Replacement," Roads and Streets, Vol 89, No. 10, Oct 1946, pp 71-73.

Description of removal and reconstruction of sidewalk, sidewalk brackets, railing and other details of river bridge at Hamilton, Ohio; details or reinforcement of concrete brackets.

D-22 Cohen, A. B., "Repairs to Spruce Street Bridge, Scranton, Pa.," Proceedings, American Concrete Institute, Vol 43, Nov 1946, pp 241-248.

Repairs and reinforcements of the Spruce Street Bridge built in 1893 over the Lackawanna Railroad and Roaring Brook in Scranton, Pa., are described. The effective application of the "Alpha System-Composite Floor Design" reinforced the floor system at the same time a new concrete floor slab was laid.

1947

D-23 Chadwick, W. L., "Hydraulic Structure Maintenance Using Pneumatically Placed Mortar," Proceedings, American Concrete Institute, Journal, Vol 43, Jan 1947, pp 533-548.

Where exposed to frequent freezing and thawing cycles while saturated, concrete in hydraulic structures and on snow-covered flat or nearly flat surfaces suffers deterioration which requires repair before the strength of the affected structure is seriously impaired. The principal causes of deterioration are enumerated, and several methods of customary repair are discussed, with special mention of the methods employed in making repairs to a number of hydraulic conduits and dams in the High Sierras of California.

D-24 Bassett, W. M. and Clair, M. N., "Repair of Concrete Chimneys with a Minimum of Interference with Operation of Boilers," Proceedings, American Concrete Institute, Journal, Vol 43, Feb 1947, pp 653-668.

Demolition of a concrete chimney at public utility plant provided an opportunity to study the relation of SO_3 content of the cross section of the shell to the condition of the concrete. This data used to supplement physical examination in

determining necessity for repair of two other chimneys at same plant. Wartime conditions required repair without plant shutdown. Methods employed and results obtained are described in detail.

D-25 Simonds, A. W., "Contraction Joint Grouting of Large Dams," Proceedings, American Concrete Insitute, Journal, Vol 43, Feb 1947, pp 637-652.

The practice of the United Sates Bureau of Reclamation is to build large dams in blocks, bounded by keyed joints to minimize cracking caused by shrinkage which is due to dissipation of the setting heat of the concrete. After the concrete reaches its minimum temperature, the voids in the joints between the blocks are filled with cement grout under pressure to create a concrete monolith. This paper describes experiences in the development of the present grouting techniques and the actual process of grouting contraction joints in large concrete dams. Special reference is made to grouting the contraction joints at *Shasta* Dam.

D-26 Keatts, B. D., "The Maintenance and Reconstruction of Concrete Tunnel Linings with Treated Mortar and Special Concrete," Proceedings, American Concrete Institute, Journal, Vol 18, No. 7, Mar 1947, pp 813-826.

Defects in concrete tunnel linings such as disintegration, seepage, honeycomb, cracking and structural failures and faulty conditions in earth and rock formations through which tunnels have been bored have been corrected with treated mortars, a special concrete, and through unconventional methods of applying them.

This paper includes a general discussion of tunnel maintenance problems and a description of the mortar, concrete, and methods employed in the repairs of four selected tunnels.

D-27 "Dam Refaced with Precast Concrete," Engineering News-Record, Nov 13, 1947, pp 116-120.

When frost damage to the concrete of Barker Dam near Boulder, Colorado became serious, the rather thin gravity section was thickened and a new upstream face was provided. This was done by setting up a wall of precast concrete slabs to serve as a form, welding projecting dowels to steel embedded in the upstream face of the dam and filling the intervening space with densely packed aggregate. The final step was a grouting operation of unusual scope and speed to complete the bonding of old and new portions of the structure while the dam was under nearly full reservoir load.

1948

D-28 Davis, R. E., Jansen, E. C., and Neelands, W. T., "Grouted Gravel Fill and Precast Slab Provide New Face for Barker Dam," Civil Engineering, Vol 18, Feb 1948, pp 26-31 and 84.

Rehabilitation of the badly disintegrated upstream face of Barker Dam, a 32-year-old, 175-ft-high concrete structure *in Boulder County, Colo., involved the* use of precast concrete slabs as forms in constructing a protective blanket of concrete varying in thickness from about 3 ft at the crest to about 8 ft at the base. Data presented herein, including techniques used in casting and erecting the precast slabs, the use of Prepakt concrete grouting procedures, and comments on the insignificant form pressures and low temperatures observed are abstracted from a paper presented before the Power Division at the ASCE Annual Meeting.

D-29 Gliddon, C., "Repairing Concrete Hydraulic Structures," Proceedings, American Concrete Institute, Journal, Vol 44, No. 7, Mar 1948, pp 513-520.

Seventeen years experience of the Gatineau Power Co. indicates that ordinary concrete, reinforced and unreinforced, can be successfully used to repair hydraulic structures. Elimination of leakage prior to surface repair, good bond between new and old concrete, and shrinkage of new concrete during setting to prevent cracking are important. A procedure for repair is outlined stressing the importance of experienced labor and supervision and briefly describing grouting, selection of materials, design strengths of concrete, preparation of surface, vibration, forms, curing, and joints.

D-30 Davis, R. E., Janse, E. C., and Neelands, W. T., "Restoration of Barker Dam," Proceedings, American Concrete Institute, Journal, Vol 44, No. 8, Apr 1948, pp 633-667.

A unique method of stabilizing and restoring a 37-year-old dam is described. A 12,500 cu yd blanket of concrete made by the Prepakt method was bonded to the upstream face and was contained behind a permanent form made of precast concrete slabs. The work of erecting the slabs and placing the coarse aggregate behind them was done in the dry during the cold winter months when severe weather conditions would have made impracticable the placement of conventional concrete. When the reservoir was nearly filled with cold water from melting snow in the mountains, and the dam was in the position of nearly maximum downstream deflection, the aggregate mass was grouted under water as a continuous operation without cold joints over the full length and height of the dam. The average maximum temperature of the Prepakt concrete mass during the hardening period was only 63° F, and usually occurred about four days after grouting.

D-31 Morris, E. H., "Reconditioning of Defective Arch in Stockport Viaduct," Journal, Institution of Civil Engineers (London), Vol 31, No. 1, Nov 1948, pp 82-90.

Reconditioning of one of 26 semicircular 3-ft thick brick arches; remedial measures consisting of insertion of steel concrete truss, replacing defective bricks, and filling cracks by cement grouting; tests to obtain confirmatory data on assumption that temperature expansion was primary cause of failure; illustrations.

D-32 Tallack, C. K., "Pressure Grouting of Gainsborough Bridge," Surveyor, Vol 107, No. 2964, Nov 26, 1948, p 634.

Open joints and cracking voussoirs of stone arch bridge, built 1791, were successfully closed by pressure grouting; work done from landing craft; injection tubes inserted in 2-in. drilled holes.

<u>1949</u>

D-33 Asplund, S. O., "Strengthening Bridge Slabs with Grouted Reinforcement," <u>Proceedings, American Concrete Institute</u>, Vol 45, Jan 1949, pp 387-408.

On the project described the negative reinforcing bars settled as much as 2-1/2 in. out of correct position. Various means for incorporating negative reinforcement at correct height in the finished structure are discussed. The method selected of grouting additional bars in grooves cut with the aid of a diamond saw is described. Tests on beam specimens made with some bars encased in the concrete and some bars grouted into diamond-sawed grooves give results identical with those to be expected for all bars normally encased; ultimate strengths conform closely to the plastic bending capacity of reinforced concrete according to design methods originated by Whitney.

D-34 Tallamy, B. D., "Control of Concrete Pavement Scaling Caused by Chloride Salts," <u>Proceedings, American Concrete Institute</u>, Vol 45, Mar 1949, pp 513-520.

Under modern traffic requirements on heavily traveled roads, salt-treated abrasives will not remove ice quickly enough. As maintenance forces have struggled to meet the demand for uninterrupted service the use of straight salts has become increasingly common. Direct applications of up to 600 lb of salt per two-lane mile are required to combat extreme icing conditions. Pavements constructed to withstand the weak brines deposited by salt-treated abrasives cannot stand up under straight salt. New pavements appear more vulnerable than those two or more years old.

The observed resistance to salt action of the oil soaked center streak of uphill traffic lanes led New York state highway engineers to investigate the feasibility of the use of dilute oil applications as a protective measure. Laboratory tests indicate successful results may be expected. In the late summer of 1948 oil spray equipment was developed in time to treat nearly 60 miles of new concrete highways, which should provide a wide base for field observation of the effectiveness of the method.

D-35 Wood, T., "Air-Placed Concrete for Renovation," Engineering News-Record, Vol 142, No. 23, Jun 9, 1949, p 71.

Kansas City landmark repaired by pneumatically placed concrete; thickness of concrete shot on old members was as great as 12 in. in some places; masonry facing backed up to thickness of 4 in. with air placed concrete; reinforcement consisted of 1/2-in. bars spaced 12 in. both ways.

D-36 Champion, S., "Repair of Concrete Structures," Reinforced Concrete Review, Vol 1, No. 12, Jul 1949, pp 477-511.

Causes and diagnosis of failure; design of new concrete for repair work such as surface treatments, treatment of joints, surface cavities and foundations; illustrated examples of damaged concrete and of repair work.

1951

D-37 Kelsall, G. S., "Cement-Gun Process and Its Application to Repair Reinforced Concrete Framework of South Shore Open-Air Bath, Blackpool," Journal, Institution of Municipal Engineers, Vol 77, No. 7, Jan 1951, pp 609-635.

Range of application of gunite; causes of failures; repair of open-air bath concrete framework; practical examples described and illustrated; kinds and causes of damages; remedial measures; expansion joints; stress analysis.

D-38 Vivian, C. H., "Concrete-Wall Surgery by Mining Methods," Compressed Air Magazine, Vol 56, No. 5, May 1951, pp 123-126.

Illustrated description of removal of section 11 by 13 ft from 24-in. thick concrete wall, by drilling row of holes and broaching material between them to make slots, and breaking out adjoining sections of concrete by plug-and-feather technique.

D-39 West, J. D., "Some Methods of Extending the Life of Bridges by Major Repairs or Strengthening," Proceedings, Institution of Civil Engineers, Vol 6, Feb 1951, pp 183-202.

Railway time schedules include intervals of inactivity in each 24 hours, or at weekends, which may be used for civil engineering works of maintenance and reconstruction requiring possession of the line.

Such periods are seldom sufficient to carry out bridge reconstruction and other necessary major works. When required, special possession facilities are arranged; these cause some dislocation to traffic, and demand for the facilities must be kept to a minimum.

As more bridges become a century old, reconstructions are becoming due at an increasing rate, which it is thought, will continue for some years to come.

Often by using suitable repair techniques, bridges may be restored to service for further longer periods with only minor interference to traffic.

Such instances are not rare; the paper shows some methods and examples of repairing or strengthening bridges with this aim in view.

Separate sections deal with considerations in the preparation of bridge repair and renewal programmes; abutment and foundation problems; arches and spandrel walls; metal bridges; and temporary works. Typical defects and methods of treatment are discussed.

D-40 ACI Committee 805, "Recommended Practice for the Application of Mortar by Pneumatic Pressure," Proceedings, American Concrete Institute, Journal, Vol 47, No. 5, May 1951, pp 709-720.

This ACI Standard presents briefly the advantages and disadvantages of pneumatically-placed mortar and establishes recommended practices for placing and mixing shotcrete, qualifications and duties of workmen, preparation of surface before shotcreting, reinforcing, sequence of application, and other items involved in good shotcreting.

1952

D-41 Minnotte, J. S., "Lock No. 5 Monongahela River Refaced by Grout-Intrusion Method," Civil Engineering, Vol 22, Oct 1952, pp 872-875.

Recent experience at Monongahela River Lock No. 5 has demonstrated that the prepacked aggregate, mortar-intrusion method affords a practical alternative to conventional methods for the resurfacing of lock walls. This lock is located at Brownsville, Pa., 56.5 miles above the mouth of the Monongahela at Pittsburgh.

The contract work included not only the removal of existing scarred concrete and its replacement with wire-mesh reinforced concrete, but also such incidental work as the furnishing and installation of structural wall armor and new corner protection, and the removal and replacement of existing corner protection, check posts, ladder rungs, handrailing and gate anchorages.

1954

D-42 Whitlam, E. F., "Autogenous Healing of Concrete in Compression," Structural Engineer, Vol 32, No. 9, Sep 1954, p 235-243.

Concrete that has failed in compression (or tension) possesses property of healing, providing fractured parts are maintained damp and in intimate contact; after experiments it was found that healing followed same form as general hardening process in concrete and that healing is dependent upon damage sustained by initial compression test.

1956

D-43 Clark, R. R., "Bonneville Dam Stilling Basin Repaired After 17 Years' Service," Proceedings, American Concrete Institute, Vol 52, Apr 1956, pp 821-838.

Bonneville Dam has passed approximately 1,000,000 cu ft per sec, believed to be a record for any dam so far as volume of water is concerned. When the project was designed and constructed, 1934 to 1938, the board of consulting engineers in approving the design predicted that the baffles

designed to absorb part of the energy of the large annual floods of the Columbia River would require renewal at 15-year intervals. The condition of the concrete in the stilling basin was observed throughout the 17 years following completion and in 1954 a cofferdam was constructed and one-half of the stilling basin was unwatered. When seen for the first time, the concrete was in better condition than expected, based on divers' reports. Special tests and hydraulic model experiments were conducted to determine to what extent conditions could be improved. Repair work was completed and the cofferedam removed before the 1955 seasonal high water.

D-44 Cook, H. K, and Kennedy, T. B., "Pressure Grouting Fine Fissures," Technical Report No. 6-437, Oct 1956, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This investigation of various grout mixtures and grouting pressures to determine their effects on the grouting of fine fissures was performed in three stages. In the first stage the lowest water-cement ratio grouts that could be pumped through cracks of 0.01-, 0.02-, and 0.03-in. thickness, formed between specially prepared concrete slabs, using 100-psi pressure were determined. Standard field grouting equipment and methods were used. The grouts investigated consisted of neat cement, cement plus fly ash, and cement plus fly ash plus Intrusion Aid. The second stage provided information on grout penetration and the quality of hardened grout films obtained at pumping pressures of 25 and 50 psi using the same grout combinations as in the first stage and an additional combination of cement plus Intrusion Aid, through crack thicknesses of 0.02 and 0.03 in. Tests were also made on neat-cement grout plus calcium lignosulfonate (RDA) at 25-, 50-, and 100-psi and on neat-cement grout plus Intrusion Aid at 100 psi. In the third stage information was obtained on the quality of hardened grout films and the penetration of 0.03-in. cracks using a 50-psi pumping pressure and grouts containing various proportions of cement, cement plus fly ash, cement plus pumicite, and cement plus opaline shale. Tests were also made for consistency, bleeding, setting time, and solubility of the hardened grout films in distilled water.

1957

D-45 Klieger, P., "Curing Requirements for Scale Resistance of Concrete," Bulletin 150, pp 13-31, 1957, Highway Research Board.

The record of field performance of air-entrained concrete pavement with regard to surface scaling resulting from the use of deicers is excellent. Approximately 15 years of field experience, together with extensive laboratory tests, have shown that the use of entrained air has solved an important pavement problem which was becoming more serious with the increasing use of chemicals for ice control.

The problem of the earliest age at which deicers, such as calcium chloride, may safely be used on new air-entrained concrete pavements is of concern to highway engineers. This concern stems from previous practical experience with nonair-entrained concrete pavements. Shortly after the introduction of the use of deicers, field surveys indicated that older nonair-entrained pavements resisted surface scaling better than relatively new nonair-entrained pavements. This led to the establishment of minimum ages at which deicers might safely be used; however, the various highway departments were far from agreement on these age requirements. A recent survey of highway department practices, conducted by Committee B-7 of the Highway Research Board, indicates that these minimum ages ranged from a few months up to 5 and 10 years. Despite the excellent performance record of air-entrained concrete pavements, many states are applying the same age requirements to both types of concrete pavement.

Only a limited amount of information is available bearing directly on this problem. This study was undertaken, therefore, to provide additional information which might interest those concerned with the use of deicers on new air-entrained concrete pavements.

D-46 Shelburne, T. E., "Pavement Condition Surveys," Spécial Report 30, 1957, Highway Research Board.

This report was prepared as a step towards establishing uniformity in the reporting of condition surveys of pavements.

The first part of the report outlines various types of condition surveys and suggests methods of making them. Appendices A and B contain definitions of construction types, components, and defects or manifestations together with illustrations. These definitions have been listed in order to present a more uniform understanding of just what is meant by the terms frequently used in making condition surveys.

Appendix C contains suggested forms. In the preparation of this report it was not the thought of the Committee to dictate the type of forms to be used in studying various pavements, but rather to point out what they considered the

minimum amount of information which would make the surveys of maximum use to others than those conducting them.

1958

D-47 U. S. Army Engineer North Central Division Laboratory, Corps of Engineers, "Investigation of Epoxy Resin System for Structural Repair of Concrete Pavement," Jul 1958.

The purpose of this investigation was to determine the suitability of epoxy resins for structural repair material for concrete. Specifically, it was to determine a suitable formulation to use in restoring the structural strength of a concrete paving slab across a sawed contraction joint when a crack had developed near the saw cut. Both Thoikol LP-3 and General Mills Versamide 125 were investigated as polyfunctional flexibizers for the immediate purpose. Tertiary aromic amires (Rohm & Hass DMP-30 and DMP-10) were used as catalytic curing agents. The most desirable system for concrete pavement patch was found to be Epon 820 flexibized with Thiokol LP-3 and catalytically cured with DMP-10.

From the standpoint of durability and impact resistance 40 parts per 100 of Thiokol LP-3 is most desirable. At 30 parts per 100 the cured system tends to be brittle.

D-48 Heath, A. N., "Epoxy Pastes and Sealants," Nov 1958, Presented at Regional Technical Conference, Society of Plastics Engineers, Inc., Southern California Section.

Covers the uses of epoxy resins in concrete protection and repair, sewer installations, food processing, and other uses.

D-49 Gewertz, M. W., Tremper, B., Beaton, F. L., and Stratfull, R. F., "Corrosion of Reinforcing Steel and Repair of Concrete in Marine Environment," Bulletin No. 182, 1958, National Research Council, Highway Research Board.

Causes and repair of deterioration to California bridge; discussion of history, character and extent of deterioration, inspection, estimating and repair procedures, basis of contract payments, and costs of repair; investigation of basic causes of distress and two possible methods for alleviating corrosion.

1959

D-50 U. S. Army Corps of Engineers, Rigid Pavement Laboratory, "Instructions for Repair Procedures for Uncontrolled Cracks and Spalls in Rigid Pavements Using Epoxy Resin, Grouts, Mortars, and/or Concretes," Technical Memorandum No. 2-11, May 1959.

The application of epoxy resin systems in the present pavement field is a relatively new development. Inasmuch as epoxy resin systems must be tailored to specific applications, two purchase descriptions have been prepared for Corps of Engineers and/or contractors procurement of suitable epoxies for the subject uses.

In the report the repair procedures described are fully applicable to existing U. S. Army Airfield maintenance operations.

D-51 Forrester, J. A., "Use of Gamma Radiography to Detect Faults in Grouting," Magazine of Concrete Research, Vol 11, No. 32, Jul 1959, pp 93-96.

Technique used to examine prestressed beam which had been badly grouted intentionally; faults were detected and their presence confirmed by breaking open specimen; use of radioactive cobalt of 275 mc strength in shape of right cylinder 2 mm long and 2 mm in diameter.

D-52 Stevens, D. E., "New Steel Backbone for Old Concrete Bridge," Civil Engineering (New York), Vol 29, No. 7, Jul 1959, pp 54-56.

Rebuilding of 50-year-old deteriorated viaduct, carrying 15,000 cars per day in Atlanta, Ga., with no interruption to

traffic; 21- to 33-ft spans of beam-and-girder and one 64-ft span of plate girder construction; in limited space under bridge, strengthening steel pipe piles were driven by special method; pipes were plugged up with concrete and drop hammer operated inside pipe; 823 tons of structural steel used; strengthening stringers were applied and grouted to existing structure.

D-53 U. S. Department of the Air Force, "Repairs to Airfield Rigid Pavement," Air Force Pamphlet 88-116-1, 28 Aug 1959.

This pamphlet furnishes guidance for the repair of uncontrolled cracks and spalls in portland cement concrete pavements using epoxy resin systems. Included in this paper are the applications, effective temperatures, aggregates, sampling, testing, field mixing, batch size, cleaning, and safety precautions required in the use of epoxy resin concretes and mortars.

D-54 "Epoxy Resin for Worn Bridge Deck," Roads and Streets, Dec 1959, pp 93-94.

Article describes repairs to bridge deck. Procedures and results are covered.

1960

D-55 Emmons, W. F., Lavik, O., and Hornby, P. L., "Control of Cracking in TVA Concrete Gravity Dams," Journal of the Power Division, American Society of Civil Engineers, Vol 86, No. PO1, Feb 1960, p 11.

All concrete dams of TVA are of the straight gravity type. This paper outlines the methods which have been used to control cracking of mass concrete in four of the largest of these. Results include description of cracks observed during and after construction.

D-56 Goldberger, H. W., "The Use of Epoxy Resins on the New Jersey Turnpike," Public Works, Vol 91, No. 3, Mar 1960, pp 98-100.

This article describes the repairs made to the New Jersey Turnpike with epoxy resins. Covered are the type of repair, procedure, results, and future expectations.

D-57 U. S. Army District, CE, Omaha, Nebraska, "Repair of Cavitation in Concrete Immediately Downstream from Flood Control Tunnel No. 10 with Epoxy Resin," Jun 1960.

Several epoxy resin mortar and epoxy resin concrete mixtures were made and cast into simulated portland cement concrete core holes and prepared portland cement spall specimens. The most suitable gradings and batch quantities of materials were arrived at by visual observation of the working characteristics and calculation of yield of the mixtures. Half the epoxy resin mortar and epoxy resin concrete mixtures were placed in dry portland cement concrete specimens. This was done in order to evaluate the effect of moisture upon the bonding characteristics of epoxy materials in anticipation of a moisture problem in the field such as difficulty in adequately drying the portland cement concretes.

This report presents batch data for use in the field repair work at Ft. Randall dam and the findings in the placement of epoxy mixtures against dry and also moist portland cement concrete in the laboratory.

D-58 Davis, R. E., "Prepakt Method of Concrete Repair," Proceedings, American Concrete Institute, Journal, Vol 57, Part 1, Aug 1960, pp 155-172.

The prepakt method is used both in the restoration of old concrete and masonry structures and in certain types of new construction such as underwater work and work where the proper placement of conventional concrete would be difficult or impossible. The method is described, as are the materials employed. The types of repairs for which the method is particularly well adapted are given. Mix proportioning methods are discussed. Methods of test for fresh prepakt grouts and hardened prepakt concrete are given. The properties of prepakt and conventional concrete are compared.

D-59 Felt, E. J., "Repair of Concrete Pavement," Proceedings, American Concrete Institute, Journal, Vol 57, No. 8, Aug 1960, pp 139-153; Also available as Portland Cement Association Development Department Bulletin D44.

Patching of distressed areas of concrete pavements with bonded concrete can be accomplished successfully if established principles are followed. Most important is a clean, sound, old concrete surface. In addition, high quality grout and concrete, and first class workmanship are essential. Suggestions are given for cleaning and preparing the old surface, for grouting, and for placing concrete.

D-60 Kulberg, O. N., "Pneumatically Applied Mortar for Restoring Concrete Structures," Proceedings, American Concrete Institute, Journal, Vol 57, No. 2, Aug 1960, pp 183-192.

Pneumatically applied mortar is the most economical and successful means of restoring concrete structures where deterioration is relatively shallow and the restoration areas large and irregular. However, periodic protective applications are necessary in areas of severe exposure to seal hairline shrinkage and temperature cracks that may pass water and perpetuate deterioration of the parent structure.

Large deep deteriorated areas under severe exposure are economically restored by the installation of a metallic membrane.

D-61 Tremper, B., "Repair of Damaged Concrete with Epoxy Resins," Proceedings, American Concrete Institute, Journal, Vol 57, No., 8, Aug 1960, pp 173-182.

The use of adhesives and binders containing epoxy resins by California Division of Highways in repairing concrete is described. Illustrations of their use in repair work are given. The discussion includes possible variations in formulation to secure wanted properties for specific uses, methods of application that are necessary to obtain strong and durable repairs, and a typical formulation for general use.

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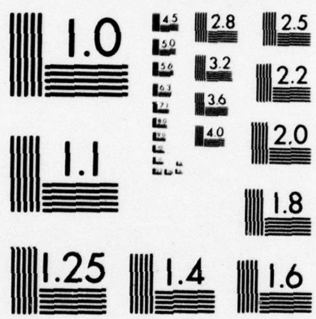

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D-62 Tuthill, L. H., "Conventional Methods of Repairing Concrete," Proceedings, American Concrete Institute, Journal, Vol 57, No. 8, Aug 1960, pp 129-138.

Some of the most important aspects of conventional methods of concrete repair and restoration are reviewed, compared, and emphasized. Particularly, factors affecting bond, permeability, cracking, durability, and appearance are discussed.

It is particularly emphasized that fully satisfactory repairs are seldom obtained without thorough inspection to insure strict adherence to all parts of the specified procedure.

D-63 "The Ability of Various Waterproofing Membranes to Bridge Cracks That Might Develop in Concrete on Which They are Applied," American Railway Engineering Association Bulletin, Vol 62, No. 559, Sep-Oct 1960, pp 153-167.

This report contains a description and the results of an investigation of waterproofing membranes fabricated with different combinations of fabrics and felts with asphalts or tars. There was no previous test for determining the behavior of a membrane, when a crack develops in the surface to which it has been applied. It was necessary first to develop a method of testing, and second to design an apparatus to permit testing a specimen under controlled conditions in order to permit measurements of the effect of the particular variable being studied.

Features of membranes that were studied included the kind and grade of bituminous materials, the kind of fabric employed, the number of piles, the bond or slippage strength and the effect of prevailing temperatures.

The temperature existing in a bituminous membrane was a major factor in its performance; therefore, in order to obtain information of temperature range in membranes in service, recording thermometers were installed on a bridge deck and maintained during a 12-month period.

The temperature-ductility relationship of many asphalts was studied at various temperatures ranging from 20^{o} to 70^{o} F. From the data obtained in these studies, curves were plotted permitting comparison of the performance of the membranes.

Temperature-pull curves were plotted of different membranes, mostly of two-ply fabric with asphalts of different specifications, also combinations of felts and fabrics and of preformed membranes.

Above-ground asphalts with two- and three-ply membranes of cottom fabric proved more satisfactory in the range of 0° to 70° F. Below-ground and synthetic asphalts, even though they stretched more at higher temperatures, did no prove as satisfactory at the lower temperature range as the above-ground asphalts.

Three- and five-ply membranes with felts and above-ground asphalts performed equally well. In comparison to membranes with fabric, the felts were as good or a little better at low temperatures, but the fabric membranes were much better from 40° F and up.

Emulsified asphalts showed little or no crack coverage ability from 0° to 70° F. Cutbacks were little affected by temperature change but did not have much stretch before failure occurred.

D-64 Roberts, J. A. and Vivian, H. E., "Improvements and Repairs to Concrete," <u>Constructional Review</u>, Vol 33, No. 10, Oct 1960, pp 31-33.

Results of experiments with epoxy resin plastic which can be used to restore tensile strength of cracked and deteriorated mortar specimens; specimens were normal, dense, uncracked mortars, seriously expanded and cracked mortars, and porous cement-deficient mortars; results of tests; use of epoxy resin also as protective coating and as adhesive between concrete members.

D-65 "Hydraulic Hammers Perforate Pavement with Rapid Blows," <u>Construction Methods and Equipment</u>, Vol 42, No. 11, Nov 1960, pp 80-82.

Repairing and widening of 3215-ft-long 66-ft-wide Anthony Wayne Bridge in Toledo, Ohio, comprising 1252-ft-long suspended span; pavement was stripped by two hydraulic hammers fitted with specially fabricated steel punchers, each operating with 14,500-lb impact; hammers cut out 6- by 9-ft blocks of 11-1/2-in.-thick pavement; repaving by use of specially fabricated Granco corrugated forms that remain permanently in place.

D-66 Westall, W. G., "Bonded Resurfacing and Repairs of Concrete Pavement," Bulletin 260, pp 14-20, 1960, Highway Research Board.

For several years the Research and Development Division of the Portland Cement Association has investigated methods and materials for bonding relatively thin layers of concrete to old pavements or floors. The laboratory tests were designed to evaluate such factors as surface cleanliness; smooth and roughened surfaces; damp and dry surfaces; cement-sand mortars and neat cement grouts for bonding courses; concrete resurfacing mix designs; and methods of placing the resurfacing concrete, including surface and internal vibration, mechanical float compaction and pneumatic pressure application. Tests were made of the effectiveness of the bond as measured by the load required to shear the concrete along the plane of the junction of the two layers of concrete. These tests indicated that the most important single factor was the condition of the old surface - its cleanness, texture, and strength or soundness. If the surface was clean and free of a weak outer skin, very good bond was generally obtained; otherwise relatively poor bond was obtained.

These laboratory investigations are described in detail by Felt.

The purpose of this paper is to discuss bonded concrete construction and its various applications to pavements, to describe projects which have been accomplished, and to illustrate the essential steps in surface preparation and construction. All the jobs discussed were constructed at airports.

1961

D-67 "Epoxies Used for Repairing Golden Gate Bridge Approaches," Pacific Road Builder and Engineering Review, Vol 97, No. 2, Feb 1961, p 25.

Replacement of frozen bearing plates on 588 concrete piers on the approaches to the Golden Gate Bridge in San Francisco have resulted in some unusual construction methods.

The simple steel and brass plate contact plates had become rusted and they had frozen together to become a fixed girder. This condition had caused the concrete girders to crack and to spall off concrete, because the girders could not expand and contract with temperature changes.

The California Division of Highways decided to replace all of the bearing plates and install new ones. Specifications called for the application of liquid epoxies on all areas where new concrete was to be bonded to old concrete.

All of the old concrete had to be chipped off by using a jackhammer. Enough concrete was removed to expose the 1-1/2-in. steel reinforcing bars and to provide sufficient clearance for installation of rocker bearings. Free movement of both the upper and lower plates of each rocker bearing is provided. One plate is welded to the reinforcing steel of the concrete girder and the other to the rebars of the concrete pedestal.

Specifications called for epoxy to serve as a gluing agent and as a grout in placement of the bearing agent. The contractor used Epocast 25A. It was first painted on reinforcing bars, the bearing agent, and the old concrete. Then it was mixed with dry sand to make a grout and packed between the concrete and bearing agent. The grout patch was then painted with the liquid epoxy and the finish concrete pour was made. One hundred fifty gallons of epoxy were used.

D-68 Levy, M., "The Use of Adhesives in the Bonding and Repair of Precast Products," Civil Engineering and Public Works Review, Mar 1961, pp 333-335, and Apr 1961, pp 495-496.

In this report are described several applications of cold setting resins for the structural repair and jointing of precast products. Resins such as the epoxy and polyester varieties are shown to give a bond and resin strength in excess of that of the concrete itself. They may be used for the repair of all types of products, pretensioned prestressed units excluded, which have become damaged due to accident or bad handling. Resins either in straight or in extended form may also be used for mortaring the faces of beams in long line for post-tensioning operations.

Air-drying resins such as emulsifiable polyvinyl acetate are shown to have applications where bond and not resin strength greater than concrete strength is required since they form very strong films.

D-69 Selander, C. E. and Mitchell, L. J., "Epoxy Resins for Concrete Construction and Repair," General Report No. 28, 17 Apr 1961, Department of the Interior, Bureau of Reclamation.

The purpose of the Bureau of Reclamation's study on epoxy resins was aimed at developing standards for use within the Bureau. Each test program was designed to include as many as practical of the variables which might affect performance.

Different types of epoxy compounds were compared under identical conditions to determine what type epoxy was suited for what purpose. Types of tests conducted by the Bureau included: Impact, Shear bond of mortars to concrete and old concrete to old concrete, Cavitation, and the performance of epoxies due to cleaning, vibration, and abrasive resistance. Results of field trail tests on the Grand Coulee Dam and Carter Lake Outlet Works are also given.

D-70 Champion, S., Failure and Repair of Concrete Structures, Wiley, New York, 1961.

The first chapters are concerned with chemical and mechanical failure of concrete and exemplify deterioration by photographs extending back over 30 years.

Methods of repair are then detailed and the merits of slurrying, rendering, gunite and spraying are discussed.

Many detailed cases are given which include undesirable features of design and construction applicable to all concrete works. A chapter is included on floors, where many failures occur. Cracks and joints are dealt with especially from a waterproofing point of view. Foundation treatment is described. Finally, a chapter on repair supervision summarizes the salient points of the work as a whole.

D-71 Gould, V. G., "Summarized Committee Report 1948-1960: Salvaging Old Pavements by Resurfacing," Bulletin 290, 1961, Highway Research Board.

Recognizing that the salvage of old pavements was a national problem, the Highway Research Board, through its Department of Maintenance, organized a committee in 1948 to assemble and disseminate information relative to prevailing practices to those agencies concerned with such work.

The first phase of committee study was to assemble information regarding practices in design and construction currently in vogue from 1948 through 1951, and was terminated with the publication of HRB Bulletin 47.

The scope of committee activity was then expanded to keep abreast of new developments in practices, methods and technique in the salvage of both rigid- and flexible-type pavements.

To this end, the committee has encouraged the presentation of papers covering experimental work and new methods and means to improve the performance of salvaged pavements, and has published replies to questionnaires dealing with specific aspects of such work.

This paper covers briefly what are considered to be the most significant studies and experimental work, completed or in progress by research agencies of highway departments and educational institutions, as reported to the Highway Research Board.

D-72 Pinkstaff, E. and Davis, W. L., "Epoxy Resin for Structural Repair of Concrete Pavement," Transactions, American Society of Civil Engineers, Vol 126, Part II, Paper No. 3121, 1961, p 154.

This paper describes tests performed in the North Central Division Laboratory of the Corps of Engineers in formulating epoxy resins that will satisfactorily repair surface defects in portland cement concrete pavements, that will bond the hardened surfaces of concrete together, and that will bond new concrete to existing concrete. It describes also the field application of the resulting epoxy resins.

1962

D-73 Finney, E. A., "Preventive Measures for Obtaining Scale-Free Concrete Bridge Structures," Bulletin 323, pp 26-42, Jan 1962, National Research Council, Highway Research Board, Washington, D.C.

This report deals with the prevention of concrete scaling common to highway bridge decks and other superstructure elements constructed with air-entrained concrete.

The term "scaling of concrete" refers here in particular to forms of concrete surface disfiguration manifested by surface laitance scale, mass pitting of small aggregate particles, and localized areas of deep disintegration.

Most of the scaling on bridge superstructures develops in curb faces, sidewalk sections, concrete railing posts, dividing strips, gutter areas, and only occasionally in the deck slab in the traffic lanes. Further, the scale pattern in most cases is generally sporadic rather than continuous. Any of

these scaling manifestations may be accelerated in various configurations by frost action in the presence of deicing chemicals. However, scaling often occurs without the presence of deicing chemicals when concrete conditions are conducive.

The problem of concrete scaling is not new to highway engineers. During the 1930's, highway engineers were vitally concerned with the problem of concrete scaling on pavements and structures. This phenomenon became more serious in northern states as the use of deicing chemicals increased, especially after World War II.

The seriousness of the situation eventually led to a concerted program of research in which many agencies participated through laboratory research and the construction of independent test pavements. The outstanding results of this early research were the discovery of the principle of air entrainment and the subsequent application of this principle to concrete construction practice for the purpose of creating more durable pavements. Although these researches established beyond any possibility of doubt the benefit of air entrainment in improving the resistance of concrete to scaling, bridge designers were reluctant to accept the use of air entrainment until several years later.

D-74 Lang, C. H., "Restoration and Protection of Damaged Concrete," Bulletin 323, pp 64-65, Jan 1962, National Research Council, Highway Research Board, Washington, D.C.

Since the thruway was first opened to traffic in the summer of 1954, over 12,666,000,000 mi of vehicle traffic have been logged on the entire system. This traffic must be kept moving at thruway speeds during all seasons. The most difficult period, in items of weather, is from November through April when icing conditions can and do occur. In the winter of 1959-1960, 50,000 tons of salt and 44,000 cu yd of abrasives were used to combat these conditions. Straight rock salt is usually used at the beginning of a snowstorm. Under conditions of freezing rain, the salt is mixed with sand in equal proportions. Storms in the 15° to 25°F range are treated with 3 parts salt, 1 part calcium, and 4 parts sand, by weight.

Cinders are not used except near Buffalo where they are plentiful and less expensive than sand or slag.

Generally speaking, the application of deicing agents in such quantities has had little detrimental effect on the

concrete roadway pavement. This is chiefly because all such pavement was constructed with concrete containing from 4 to 6 percent entrained air.

The structures tell a different story, however. All except those built near the end of the construction program were constructed of concrete containing straight portland cement and natural cement in a ratio of 7 to 1. The resulting air-entrainment from the natural cement used in this mixture is perhaps 2 to 3 percent and is not enough to afford the desired protection from saline solutions. Those structures containing the greater percentages of air display markedly greater resistance to damage.

One other contributing factor to the rapid deterioration of bridge pavements was the fact that these pavements were constructed as 4-in. thick wearing courses on previously built structural concrete decks. It was impossible to prevent salt water from infiltrating either the longitudinal or transverse pavement joints, from whence it found its way underneath the pavement to all parts of the bridge deck which it promptly proceeded to attack. Twofold damage was experienced. If the salt solution was strong enough, chemical deterioration resulted. If weak, freezing occurred and cracking of the thin pavement overlay resulted. The cracks afforded additional opportunity for subsequent infiltration.

In organizing thruway maintenance forces, the need was recognized for including a bridge maintenance group designed to cope with the problem. This group was tooled and trained to handle preventive and corrective maintenance and has now caught up with and arrested the progressive deterioration of concrete in nearly 800 bridges. It is expected that the damage can now be kept under control. In the absence of established precedents, common sense was used to develop the methods that have been employed and subsequently proven effective.

D-75 Maun, V. P. and Britton, H., "Examples of Repairs to Concrete in Bridges," Bulletin 323, pp 66-71, Jan 1962, National Research Council, Highway Research Board, Washington, D.C.

This paper explains the belief that concrete got stronger with age and that there would never be a maintenance problem. As a result of this belief concrete was used with great confidence, assured that it was an everlasting construction material. Even when steel was used in bridges, it was encased in concrete, certain that it would never have to be painted and that it would be forever protected from rust.

But it has been discovered that this confidence was misplaced. Hundreds of structures containing unsightly patches of deteriorated concrete now exist. In many cases, the concrete is less than five years old.

This paper also mentions two main objectives in the bridge repair work: (1) To restore the structural strength and appearance of the concrete. (2) To protect all concrete, both new and old, from future damage due to weathering and deicing chemicals.

D-76 Shelby, M. D. and Ledbetter, W. B., "Ice Prevention on Bridge Decks," Research Digest, No. 62-1, Jan 1962, p 4, Texas Highway Department.

Results of a series of tests using heating cables in the deck of a bridge to prevent icing are reported. The twin bridges (grade separation for City View Drive) chosen for this research study are located northwest of Wichita Falls on US 287. A description of the project, including specifications, is presented along with a discussion of the results of the tests performed during a cold period beginning January 24, 1961, and lasting through January 29, 1961. Although a limited number of tests were performed during this period, some observations concerning effect of slab thickness, cable spacing and depth of heating cable embedment are made.

D-77 Wakeman, C. M., Stover, H. E., and Blye, E. N., "Glue! For Concrete Repair," Materials Research and Standards, Vol 2, No. 2, Feb 1962, pp 93-97.

Some large structural cracks appeared in a number of concrete pile caps in a wharf at the Port of Los Angeles. The alternate to healing the cracks with epoxy resin was to demolish the wharf deck and reconstruct the beams and deck with new concrete. It was estimated that the epoxy repair would cost only half as much as reconstruction. Preliminary testing of the cracked concrete and field and laboratory tests leading to the selection of epoxy resin are described.

D-78 Mackenzie, T. T., "Thin Epoxy Layer Restores Concrete Bridge Deck," Civil Engineering (N. Y.), American Society of Civil Engineers, No. 3, Mar 1962, p 42.

This report deals with the concept that a combination of epoxy resin paving cement and aggregate should protect concrete against water and frost damage. It also includes epoxy coal tar compound and its structural modifications. Described in this report is the method of applying the resin.

D-79 Harder, P. B., "Epoxies Speed Bridge Repairs," Public Works, Vol 93, No. 7, Jul 1962, pp 90-91.

Advances of methods in use of epoxy resin for filling voids beneath metal expansion plates in bridge decks and binding nonskid grit to steel bridge deck grating surfaces; plates are drilled and tapped to accept grease fittings through which epoxy is pumped by gun to reestablish bond on loosened bridge expansion dams.

D-80 ACI Committee 201, "Restoration of Deteriorated Concrete," Proceedings, American Concrete Institute, Journal, Vol 59, No. 12, Dec 1962, p 1807.

This report presents recommendations for materials and methods to obtain concrete with maximum resistance to deterioration, to preserve concrete against deterioration, and to restore deteriorated concrete. The report specifically excludes consideration of erosion in hydraulic structures and fire resistance of concrete which are in the province of other ACI committees. Recommendations are made with respect to freezing and thawing, the use of chemicals for ice removal, aggressive chemical agents, abrasion, corrosion of steel, reactive aggregates, and the restoration of deteriorated concrete.

D-81 McGovern, E. W., "Protection of Portland Cement Concrete from Deleterious Effects of Ice Removal Chemicals," Highway Research Abstracts, Vol 32, No. 11, Dec 1962.

This paper describes field and laboratory experience over a 5-yr period on the effectiveness of a coal-tar coating to prevent deterioration of concrete from the effects of ice removal chemicals.

The laboratory experience covers observations made on samples of concrete sealed with a coal-tar coating and immersed in solutions of calcium chloride and sodium chloride and subjected to repeated cycles of immersion and evaporation - and also repeated cycles of freezing and thawing.

The field experience describes observations made in New York State, Ohio, Pennsylvania, and Connecticut on the effect of a coal-tar coating in preventing deterioration of concrete on bridges, highways, and gutters due to the action of ice removal chemicals.

D-82 Perry, B. F., "Subsealing of Concrete Pavements," Bulletin 322, pp 30-33, 1962, Highway Research Board.

This paper concerns the experiences in District No. 4 of the New York State Department of Public Works with the salvage and restoration of old concrete pavements. These pavements were pumping badly and due to loss of subgrade support were consequently being weakened under the pounding of heavier and greater volumes of traffic. These experiences cover a period since 1948. Most of these pavements were constructed in the late 1920's and early 1930's and had been subjected to severe use. Also, they were not built to the present standards of foundation and subgrade construction, and were laid on a variety of soils prevalent in western New York. The methods used, their application, and the results obtained, are discussed.

The effect of this work has been to restore the foundations of hundreds of miles of pavement and adapt them to present-day traffic through widening and serving as bases for asphaltic concrete overlays at an economical cost. The net result has been consistent rehabilitation of a 1400-mi highway system meeting present demands of traffic.

1963

D-83 Clarke, A. T., "Repair of Prestressed (Post-Tensioned) Concrete Beams After Damage by Fire," The Structural Engineer (London), Vol 41, No. 5, May 1963, pp 161-162.

Describes the repair carried out to the soffit and sides of precast prestressed beams damaged by fire. The method used involved full live loading of the construction to simulate the conditions of the original design as it concerned the state of stress in the concrete. The full loading condition also provided a satisfactory test of the composite construction and the combination of prestressed concrete and cast-in-place reinforced concrete acting together as a continuous structure.

D-84 Riley, O., "Bridge Deck Repair Technique," Public Works, Vol 94, No. 5, May 1963, pp 127-129.

Methods of correction employed in bridge deck repair works at Passaic River Bridge, New Jersey; 3-point repair program includes replacement of seriously damaged slabs and those which indicated incipient failure, experiments with most promising repair techniques for moderately damaged slabs, and search for methods to reduce future spalling.

D-85 Scholl, S. E., "New Plates Save Old Bridge," American City, Vol 78, No. 5, May 1963, pp 110-111.

Repair techniques for strengthening old arches by using corrugated metal liner plates to bolster old double-arch stone bridge, Rockford, Ill.; concrete, pneumatically placed against rolled wire mesh, seals edges of liners.

D-86 Whitaker, A. S., "Waterproofing of Bridge Decks," Roads and Road Construction (London), Vol 41, No. 486, Jun 1963, pp 162-165.

Discusses the methods for preventing ingression of water into a bridge, of which the following are regularly used:

1. The addition of waterproofing agencies to concrete.

2. Painting concrete surfaces with bitumen or similar proprietary bituminous materials.

3. The use of asphalt surfacing to the roadway and hard shoulders in conjunction with concrete slab or in-situ paving to the central reserves and remaining areas of the verges.

4. Mastic asphalt laid over the bridge deck and ends in one or two layers.

5. Waterproof sheeting laid in single or double course work.

6. A combination of asphalt surfacing to roadway areas and either mastic asphalt or waterproof sheeting to the remaining areas of the bridge deck and vertically at the ends.

D-87 Jenkins, D. B., "Protection and Repair of Bridge Decks," Better Roads, Vol 33, No. 8, Aug 1963, p 21.

This report presents methods and materials that can be used to repair decks and to prevent deterioration. The report specifically includes methods such as linseed-oil protective coating, spray-on water repellents, colorless seals and troweled on thin epoxy-sand coating.

D-88 Westall, W. G. and Gillette, R. W., "Concrete Pavement Repair With Bonded Patches," Military Engineer, Vol 55, No. 368, Nov-Dec 1963, pp 434-436.

Successful uses of bonded patches are cited dating back to 1913. Proper methods are then described including the removal of all loose or unsound material, air blowing or brushing clean, cleaning and etching with hydrochloric acid, flushing with water until a neutral reaction with pH paper is obtained, brushing with a thin coat of freshly mixed sand-cement grout, filling with mortar or mix, finishing and jointing. Use of these methods on a parking apron of an Air Force base, on the Ohio Turnpike and on Ohio State Highways is briefly described.

D-89 Maun, V. P., "Rehabilitation of Two Concrete Arch Bridges," Highway Research Record No. 11, pp 66-74, 1963, National Research Council, Highway Research Board, Washington, D.C.

Extent of damage encountered, methods used to repair and protect concrete, and unit costs of various contract items

during extensive repairs made to long concrete arch bridges at Troy, and Glens Falls, NY, are discussed.

D-90 Riley, O., "Bridge Deck Repair Techniques on New Jersey Turnpike," Highway Research Record No. 11, pp 50-61, 1963, National Research Council, Highway Research Board, Washington, D.C.

Comprehensive program of Turnpike Authority to investigate and rehabilitate concrete deck of Passaic River Bridge; maintenance of deck slab failures which occurred in approach spans of 6-1/2-in. reinforced concrete deck caused by surface spalling is described.

1964

D-91 Blackwell, F. H., "Problems in Bridge Maintenance," Public Works, Vol 95, No. 2, Feb 1964, pp 94-96.

Methods used in repairing scaling and deterioration of bridge decks; main recurring item of maintenance on bridges is cleaning and sealing expansion joints and small cracks on deck slab; in some instances when surface damage is slight, it is desirable merely to seal bridge slab or patch with cold-tar emulsion preparation; use of chemical deicing salts during snow and ice removal operations will cause rapid deterioration of exposed steel surfaces if residues are not promptly cleaned from steel members.

D-92 Papp, R. A., "Innovations Simplify Pier Extension and Repair," Civil Engineering (N. Y.), Vol 34, No. 7, Jul 1964, pp 48-50.

Pier extension and repair at New York City's Tallmans Island sewage treatment plant used only one size of precast channels for the deck of a new pier and has a post-tensioned thin slab as a new surface over a deteriorated concrete deck. Creosoted pile bents 14 ft on centers are capped with cast-in-place concrete. Precast channel-shaped units 3 ft wide, of concrete 4 in. thick, span between bents to provide top-quality concrete for exposure to salt wave splash and to act as a form for a cast-in-place deck. Over the deteriorated

deck of the old pier a slab 6-7 in. thick was placed with separation between the two to permit sliding. This was post-tensioned in 130- and 140-ft lengths by Freyssinet tendons.

D-93 MacKenzie, I. D., "Inspection and Maintenance of Concrete in Service," Proceedings, American Concrete Institute, Vol 61, Nov 1964, pp 1345-1358.

A continuing inspection by nonoperating personnel was organized some 20 years ago to assess the condition of structures making up a large hydro-electric power system. The purpose of this program is to insure that all structures are maintained in such condition that they can safely perform all functions for which they were designed. A secondary result of the inspection is the virtual elimination of major unforeseen maintenance expenditures.

As a part of this service, the cause of deterioration of structural materials is determined, if possible, before recommendations for repair complete with cost estimates are submitted to the owner. The program has been developed to such a stage that major items of concrete maintenance can be scheduled 5 years in advance, with a tentative schedule drawn up for the following 5 years.

This paper is limited to methods of concrete inspection and maintenance. Methods of concrete repair found to be suitable in the area, which extends to the southerly limit of the boreal or northern climatic region, are described briefly.

D-94 Salkowski, A. S., "Face Lifting for Bridge," Public Works, Vol 95, No. 12, Dec 1964, pp 64-67.

After it was discovered that Earles Road Bridge, a three-span reinforced concrete structure which stretches across four tracks of Pennsylvania Railroad, had failed, several studies were made to determine feasibility and financial practicality of replacing bridge, utilizing existing abutments with minor alterations and eliminating piers replacing bridge in toto as single span bridge with realigned approaches, or repairing bridge; tests resulted in decision to repair bridge; repair procedure is described.

D-95 "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures," NCHRP Report 1, 1964, National Research Council, Highway Research Board.

Study involved field inspection of 238 different concrete repair projects throughout 26 states and District of Columbia; concrete repair programs being conducted by state highway departments, by toll facility commissions and by several local government agencies were reviewed; comprehensive search of existing literature on subject of repair of deteriorated concrete was made and information was developed through field inspection on ability of existing repair procedures and materials to restore structures to their original design state and to study and report on economic aspect of methods and materials.

D-96 "Fast Concrete Pavement Patching," 1964, Concrete Information Bulletin, Portland Cement Association.

When concrete patching damage, such as spalling or scaling, does not extend the full depth of the pavement, bonded concrete patching is the most efficient and economical means of repair. Such repairs can be made rapidly, and the pavement can be reopened to traffic within a few hours.

Report presents techniques on preparing and bonding the damaged surface, and advice on concrete mix design, placing, and curing.

D-97 Harem, F. M., "Maintenance and Repair of Concrete Reservoirs," Journal, American Water Works Association, Vol 56, No. 9, 1964, pp 1160-1166.

A general discussion with special reference to the correction of excess leakage, unsightly appearance, and contamination through roof and wall joints or cracks. The application, to part or all of the internal surface of impermeable membranes (PVC, bitumen, bitumen-plastics, butyl rubber) is described, with some practical experiences being reviewed. The repair of expansion joints and of wall cracks and spalling is also reviewed.

D-98 Meeker, E. W. and Warnes, C. E., Jr., "Thin Bonded Concrete Repairs on the Ohio Turnpike," Highway Research Record No. 61, pp 43-47, 1964, Highway Research Board, Washington, D.C.

Thin bonded concrete patches are used on the Ohio Turnpike to repair damage to bridge deck and roadway pavement largely resulting from scaling and/or spalling due to freezing and thawing. The repair methods are described as well as the rigid controls set up for this method of repair.

D-99 West, A. L., "Rehabilitation of Deteriorated Bridge Slabs," Highway Research Record No. 61, pp 36-42, 1964, National Research Council, Highway Research Board, Washington, D.C.

Review is presented of methods and procedures utilized by Central Maintenance Engineering Div of Port of New York Authority to rehabilitate concrete bridge decks, improve riding surfaces and provide maximum protection against effects of deicing chemicals and elements.

1965

D-100 "Repairing Cracked Concrete Road Slabs," Roads and Road Construction (London), Vol 43, No. 505, Jan 1965, p 13.

A new and rapid method of inserting a rubber joint to repair cracks and prevent further cracking in concrete roads has been developed by the Road Research Laboratory in conjunction with construction companies. The method was first tried out experimentally on the concrete section of the M. 1 and M. 10 after irregular cracking had appeared on the surface. The cracks were several miles long, longitudinal with the road and irregular in contour. It was important that the filling be flush with the road surface and absorb any movement at the crack to avoid further cracking and spalling. The method was successful on the experimental length of about 300 yd, so about 5 miles of the cracks were repaired during the autumn of 1964.

The rubber is an extruded wedge-shpaed neoprene sponge, 1 or 1-1/2 in. deep and 3/8 in. thick at the base tapering to 3/4 in. at the top and keyed along the length. It is

softened and lightened by having holes longitudinally through its length; through these holes are run one or two lengths of malleable wire of suitable gage.

The crack is broken out to a depth and width of 1 to 1-1/2 in. and 6 to 9 in., respectively. The preformed rubber strip is laid along the line of the crack; the wire core enables the strip to take up and retain the irregular contour of the crack. The excavated area on either side of the rubber strip is then filled with an epoxy-resin/sand mortar, which retains a bond with the strip by virtue of its keyed edge shape.

D-101 Pope, D. R., "Epoxy Protection at Milford Dam," The Military Engineer, Vol 57, No. 376, Mar-Apr 1965, pp 119-120.

A brief description is given of the use of epoxy resin for the protection of outlet works from water-erosion action.

D-102 "Bridge Deck Gets New Surface," Western Construction, Vol 40, No. 4, Apr 1965, pp 102-103.

Application of a thin overlay of an epoxy-sand material concludes the reconstruction of the San Francisco-Oakland Bay Bridge. Contractor used special mix-and-spray trucks plus hand spreading of surfacing sand.

D-103 Pirsch, L., "The Reinforcement of Old Concrete Surfaces by Resurfacing," No. 63/64, Apr 1965, Mitimeyer, Germany.

The construction of 12-cm thick concrete blankets and dowelling of the cross-joints used in the first test proved to be insufficient. Thrust anchors between old and new surfacings were also inadequate. In the second and third test series, the new surfacings were reinforced with at least 15 cm thickness with special treatment of the longitudinal and transverse joints. The third test section covered 8700 square metres. It was made in 1963 and showed no defects under heavy traffic loads, apart from two transverse cracks (assembly faults). This proves that even old, heavily cracked concrete surfacings can be reinforced, widened and adapted to modern traffic conditions.

D-104 "Epoxy Repairs Cracked Beams," Engineering News-Record, Vol 174, No. 22, Jun 1965, p 48.

Brief description of repairs made to concrete craneway with epoxy resins.

D-105 Lazarr, T. R. L., "Waterproofing Below the Ground Line," Civil Engineering (N. Y.), American Society of Civil Engineers, Vol 35, No. 6, Jun 1965, p 73.

Water penetration through walls, joints, and porous materials below the ground line is a serious problem in many structures. Cracks in concrete and masonry walls, frequently caused by settlement or shrinkage, permit water to seep in. Bentonite in a new panel form may offer a dependable solution to the problem.

A method commonly tried for the protection of foundation walls below ground level is to brush or spray on a thin coating of cutback asphalt emulsion. This is widely used because of its low cost, \$0.02 to \$0.05 per sq ft. It will seal some pores for a time but will not bridge cracks or provide protection at cracks or joints that open up after it has been applied.

At a cost of \$0.20 to \$0.35 per sq ft, asphalt compounds containing fibers of glass or asbestos can be applied by special spray guns or troweling. The fibers provide some flexibility but may not prevent water penetration through newly formed cracks as the material has a tendency to dry out.

Membrane waterproofing is the next step. A coat of viscous material is troweled on the wall, and cotton, jute or fiberglass fabric is embedded in it. Sometimes three or more coats are used to protect against the hazards of puncture in backfilling. The cost may be \$0.60 to \$1.00 per sq ft.

A panel made of paper, filled with finely-ground bentonite clay, has practically the same chemical constituents as clay but can be better described as a swelling clay. When water touches it, the wetted surface forms a jelly or putty that halts the flow of water. This material never loses its ability to swell and is compatible with all building materials and soils.

Prepared in a panel it can be easily applied to vertical surfaces. American Colloid Company produces the panels and calls the product Volclay Impedance Panels. The panels can be lapped 1 in. over each other and attached to the foundation wall by nails or power staples, or by a few globs of adhesive - some means of attachment just strong enough to keep them in place vertically until backfilling can be completed. The cost is low - much more than for painted-on cut-back asphalt emulsion but much less than for other methods.

D-106 "Crash 'Dental' Job Eases Runway Bumps," Engineering News-Record, Vol 175, Jul 1965, p 112.

Repair job on rigid pavement runway at Wright-Patterson AFB. The pavement, containing unsuitable aggregate and less than desirable cement, was studied for best repair methods. Procedures called for cutting and chipping back to sound concrete, coating the cavities with epoxy grout and replacement with concrete. It was also decided to carry the removal work 1/4 in. into sound concrete. Spray equipment proved unsatisfactory in applying polysulfide epoxy to cavity surfaces, so hand brushing was used.

D-107 Blake, L. S. and Pullar-Strecker, P., "Epoxy Resins for Repair of Concrete," (with comments by M. W. Franke), RILEM Bulletin No. 28 (Reunion Internationale des Laboratoires d'essais et de Recherches sur les Materiaux et des Constructions), Sep 1965, pp 25-29.

Epoxy resins are being used in Great Britain for repair of concrete but, because of their high cost, this use is generally limited to repair of small areas. For repair of larger areas, or on roads where it is possible to close traffic for 7 days, the alternative cheaper method of applying a concrete re-surfacing is more frequently applied. In general, experience with epoxy resins has been satisfactory but some failures have occurred due to faulty application or to lack of knowledge of the properties of the resin and hardener. It is considered that the use of epoxy resins could be extended to a much wider field of repair work if more information was available on their physical and engineering properties; manufacturers of resins have little information on these properties. With these problems in mind, the Cement and

Concrete Association has made a preliminary but systematic study of the properties of epoxy resin and a full report is being prepared. British manufacturers have been given the results of this work and the Association has urged them to carry out similar more detailed tests on their own materials.

D-108 Stig, N., "Repairing and Protection of Concrete With Epoxy Resin - Views and Experiences," Cement Och Betong (Malmo), Vol 40, No. 4, Dec 1965, pp 345-360.

Swedish practice in connection with the use of epoxy compounds for repairing concrete structures and other purposes is described. Basic recommendations for insuring adequate performance are given . A number of interesting examples illustrating the use of epoxy materials in connection details of prefabricated structures are given.

D-109 Diernat, F., and de la Jarrige, J., "Use of Resins for Repairing Concrete Grouting Cracks, and Waterproofing the Face of a Dam," (Translation by Van Tienhoven, J. C.) Translation No. 65-4, 1965, U. S. Army Waterways Experiment Station, CE, Vicksburg, Miss.

Despite the care taken in the preparation and placement of concrete in hydroelectric installations, certain defects such as cracks may develop as a result of unforeseen circumstances. Resins, however, are becoming more popular in the corrective measures taken to solve some of these problems.

In this report the authors discuss some of the properties of the various materials that can be used for grouting capillary cracks, laboratory results of tests made on resin grouts, and the procedure to follow in the repair of a dam.

D-110 Gillette, R. W., "A 10-Year Report on Performance of Bonded Concrete Resurfacings," Highway Research Record No. 94, 1965, pp 61-76.

Approximately 15 small and large bonded concrete overlay projects constructed over the past 10 years on both highway and airfield pavements are described. Because techniques

of constructing these projects have been amply covered previously, only performance of the overlays under ordinary usage is considered.

The performance of seven projects was surveyed in 1961. The survey method is outlined and information determined in the 1961 survey, one made in 1964, and eight additional projects. Results are tabulated of tests of core samples and bond interface. Some areas of distress on the performance of the overlay are discussed. Good bond must be the primary goal, but a loss of bond does not appear to impede the performance of a bonded concrete overlay in long-term continuous use.

D-111 Johnson, S. M., Deterioration, Maintenance, and Repair of Structures, McGraw-Hill, 1965.

One of the purposes of this text is to describe some of the experiences of the author and of others in detecting and repairing deterioration and so to establish some of the necessary liaison between the designer, builder, and maintenance engineer and to acquaint designers and construction personnel, in general, with potential problem areas of which, lacking experience in maintenance, they might be otherwise unaware.

For each of the principal classes of construction (steel, concrete, and timber), the data are presented in two parts. The first part discusses types of deterioration, identifies their cause or causes, and describes details and procedures in design and construction which may be employed to prevent or minimize their occurrence. Examples are given of details and practices which are known to or are likely to give unsatisfactory results. The application and importance of the following basic principles are emphasized:

(1) Selection of the proper construction materials as related to site conditions, conditions of exposure, and use of the structure.

(2) Attention to the details of design and their importance with respect to the overall design concept.

(3) Insistence on proper construction practices.

The second part of the text discussion of each class of construction concerns itself with the detection and correction of such deterioration as does occur. Details or references as to suitable methods of repair are presented. Procedures employed in specific instances are detailed, and the success (or failure) of these procedures is noted. The

necessity for the provision and careful execution of a properly conceived program of inspection and minor preventive maintenance is emphasized as a means for arresting and, to some extent, preventing serious forms of deterioration. A chapter concerned with the strengthening of existing structures has been included, as this subject is ancillary to that of rehabilitation.

D-112 "Surface Preparation of Concrete for Coating," Materials Protection, Vol 5, Jan 1966, pp 84-86.

Before coating, a suitable method of surface preparation for concrete must be used to assure desired end results will be obtained economically. Owner and contractor must have a clear understanding of the required end results and set them in specifications. Coating supplier must provide his recommended procedures for surface preparation requirements before application of his material. Concrete surfaces must be free of chemical contamination, free of laitance, be strong enough to support the coatings, must be well cured, and dry.

1966

D-113 Nee, J. W., "Some Developments in Protective Coatings," Materials Protection, Vol 5, No. 4, Apr 1966, pp 27-29.

Some recent developments in protective coatings are discussed. Article does not attempt to cover all types of coatings but rather to present a brief introduction on recent developments and modifications in a few coating systems.

D-114 ACI Committee 515, "Guide for the Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion-Resistant Materials," Proceedings, American Concrete Institute, Journal, Vol 63, No. 12, Dec 1966.

The resistance of concrete to chemical attack may often be enhanced or maximized by careful attention to concrete proportioning, mixing, placing, and curing procedures.

However, in a number of situations concrete must be protected by barrier materials which prevent contact with the chemical agent. Materials available for protection have been classified here, and tables have been provided as a guide for protection against specific agents. Methods of application with consideration for both effectiveness and safety, are discussed. The report is intended to serve as a guide prior to consultation with experts regarding the specific situation.

D-115 Stalb, F. C., "Full-Depth Concrete Pavement Repairs on the Ohio Turnpike," Highway Research Record No. 146, pp 17-27, 1966.

Full-depth concrete patching is used to repair damaged sections of pavement on the Ohio Turnpike. Because of heavy traffic demands, methods have been developed to reduce the amount of time normally necessary for this type of repair.

One major time-saving practice is sawing of the concrete to be replaced into 2- by 3-ft pieces which are removed intact. Another is a rapid method for drilling holes in the vertical faces of the exposed concrete for placement of dowels. A program of rigid control of the concrete mix and placing, finishing, and curing of the concrete results in high-quality repairs expected to be permanent.

The work is so scheduled that all lanes are completely open to traffic during the weekend periods.

<u>1967</u>

D-116 Westall, W. G., "Surface and Full-Depth Patching," <u>Roads and Streets</u>, Vol 98, Feb 1967, pp 91-94.

Concrete used in pavement patching should provide high early strength, low drying shrinkage and durability. These properties derive from careful selection of materials and the mix design. Several ideal mixes are described and a step-by-step procedure is outlined. Limited areas of structural damage in otherwise good concrete is repaired by full-depth patching. Blow up at joints, multiple cracking due to differential settlement or heaving of the subgrade and the repair of utility cuts are examples of conditions requiring full-depth patching. A thorough and complete plan for full-depth patching is given.

D-117 "States Escalate Bridge Deck Battle," Engineering News-Record, Vol 178, No. 18, May 1967, pp 47-52.

In one of the annual rites of spring, highway bridge and maintenance engineers in the ice-and-snow belt again are glumly surveying one of winter's seemingly inevitable legacies - cracks, spalls, exposed reinforcing steel, even holes, in countless concrete bridge decks.

The problem is greatest on heavily traveled routes in states where motorists demand "bare-pavement maintenance" with consequent heavy applications of chemicals to remove ice and snow. But damage is by no means confined to those areas.

The article discusses methods of repair. Concrete is used by many states, but bituminous materials and epoxies are also used.

Prevention methods used by many states, such as coating with boiled linseed oil, are discussed.

D-118 Walsh, R. J., "Restoring Salt-Damaged Highway Bridge," Civil Engineering (N. Y.), American Society of Civil Engineers, Vol 37, No. 5, May 1967, pp 57-59.

The author describes the methods used on the New York State Thruway to repair bridge structures damaged by deicing chemicals and repetitive wetting. These included: the use of a mixture of linseed oil and mineral spirits for curbs, walks, fasciae, and pylons; a gilsonite asphalt coating and high solids wetting agent for pier cap sides; and fiberglass cloth and summer-grade roofing mastic for pier cap tops. Methods used for waterproofing slabs and concrete restoration are also discussed. Experiments and field usage of lightweight aggregates for concrete restoration have proven that the concrete offers greater resistance to freeze-thaw cycles.

D-119 Thomas, D. L., "Inspection and Maintenance of Highway Bridges," Surveyor, Vol 130, No. 3925, Aug 26, 1967, pp 17-19 and 22.

Inspection is performed on approved form with county bridge number and name; metal corrosion, paint deterioration,

concrete spalling and other defects are noted; determination of repair procedures on basis of available funds.

D-120 Duvall, B. U.,"Rigid Pavement Maintenance for Airfields," Journal, Aerospace Transport, American Society of Civil Engineers, Vol 93, No. AT 1, Paper 5457, Sep 1967, pp 57-76.

The advent of jet aircraft has necessitated a reevaluation of pavement maintenance with respect to smoothness and reducing the probability of foreign object (debris) damage to jet engines and tires. The repair of spalled joints is one facet of rigid pavement maintenance for which repair techniques and material have been developed and successfully used. The portland cement grout bonding technique (PCA-acid etch), using portland cement mortars or concretes, is discussed briefly and referenced. The recently developed method using epoxy resin mortar or concrete is explained in detail using an actual major repair project accomplished under quite adverse temperature conditions. The advantages and disadvantages of both methods are mentioned and performance is cited.

D-121 "Epoxy Adhesive Injection Technique Fills Cracks, Upgrades Concrete Floor Slab," Plant Engineering, Sep 1967.

Structural Concrete Bonding (pressure injecting of epoxy adhesive into cracks in concrete) was used to restore a severely cracked plant floor. A 5-in-thick reinforced slab on the second floor of International Harvester's truck assembly plant in San Leandro, California had structurally declined from its original design strength of 200 lb per sq ft to a floor loading capacity of 80 lb per sq ft.

Epoxy repair restored the slab to a loading capacity of more than 160 lb per sq ft, at less than one-third the cost of the least expensive alternate method considered. And, there was no appreciable increase in weight.

D-122 Warmisham, B., "Preventive Maintenance," Journal, Institution of Highway Engineers, London (UK), Vol 14, No. 9, Sep 1967, pp 29-32.

Preventive maintenance has positive benefits, of which the most significant perhaps are the elimination of some time-honoured operations that the scheduling and programming of maintenance operations with additional attendant benefits has made a practical possibility. Labour is released from maintenance and employed more productively on improvements. The reduction in the maintenance labour forces results in overall savings and better jobs for the remaining men. A higher standard of maintenance will result from the shorter time cycle of greater frequency of operations. Standards can be fixed by reference to the time cycle. Complete work study is a prerequisite of the system which permits production of a standard maintenance manual for universal use.

D-123 "Concrete Patching on a Runway," Civil Engineering (N.Y.), Vol 37, No. 11, Nov 1967, p 78.

This article describes procedures followed to replace spall damaged areas of a concrete runway at Sioux City, Iowa Municipal Airport. The spalled areas were located by hammer sounding, the old concrete removed and the area cleaned, the surface painted with portland cement mortar, and the fresh patch placed. Contraction joints were then put into the fresh concrete to relieve contraction stresses. When the patch had dried, joints were saved. The article describes problems encountered and solutions used.

D-124 Kreijger, P. C., "Use of Resins in the Repair of Concrete Structures," RILEM Bulletin No. 37 (Reunion Internationale des Laboratoires d'essais et de Recherches sur les Materiaux et les Constructions), Dec 1967, pp 271-276.

Preliminary results are given of an inquiry held in the Netherlands on the repairing of concrete structures situated in and outdoors. The several types of repairing mortars, based on cement, on cement with addition of polymers or purely on base of resin, do show an evident shifting in the direction of the use of repairing mortars purely on base of resins during the years of the execution of the repairings (before 1950 towards 1966).

D-125 Leitheiser, R. H., Hellmer, R. J., and Clocker, E. T., "Water Extended Resin Materials and Methods for Rapid Repair and Construction of Pavements," PROJECT: AF-8174, Dec 1967, Ashland Chemical Co., Minneapolis, Minn.

Unsaturated polyesters have been extended with high levels of water. The water-in-oil emulsions resulting from mixing polyester and water have been conventionally cured with peroxide-promoter combinations to composites with unique property combinations. Screening studies demonstrated that physical strengths of water-extended polyester (WEP) composites are dependent on resin selection, percent water, percent styrene, catalyst and promoter selection, and choice of emulsifier. By the use of properly formulated resins, the need for an emulsifier was eliminated. Initial test pours were conducted using benzoyl peroxide as catalyst. Subsequent test pours were conducted using non-hazardous liquid peroxide catalyst. The materials cost of WEP composites were established.

D-126 Parks, L. E., "Protective Coatings: New Trends in Materials and Applications," Materials Protection, Vol 6, No. 12, Dec 1967, pp 37-39.

Recent materials developments for protective coating formulations are described. Among some generic types discussed are epoxies, epoxy coal-tar, acrylates, acrylics, polyurethanes, and inorganic zincs.

D-127 Goryainor, K. E. and Antropov, V. I., "Electric-Arc Equipment for Burning Openings into Brick and Reinforced Concrete Structures," Translation of Mekhanizatsiya Stroitelstva (USSR), Vol 24, No. 2, 1967, pp 18-19.

The report discusses apparatus developed and tested for cutting openings, furrows, recesses, and offsets by electric-arc and plasma destruction of brick and reinforced concrete. The equipment is equally adapted to new construction or remodeling of existing structures.

D-128 Kubie, W. L., Gast, L. E., Cowan, J. C., "Linseed Oil for the Preventive Maintenance of Concrete," Highway Research Record No. 254, pp 61-67, 1967, Northern Regional Research Laboratory, U. S. Department of Agriculture.

Information is presented of the use of boiled linseed oil solutions and emulsions as antiscaling compounds for concrete. These linseed formulations can be easily applied to concrete with conventional spraying equipment. With the emulsion drying two hours after application, serious loss of oil during a rain appears to be eliminated. When subjected to freeze-thaw cycles in the presence of salt, air-entrained concrete highways coated with linseed oil showed increased durability compared to uncoated controls. Tests also indicated that recoating is advantageous for long-term protection. Laboratory freeze-thaw tests in water and two percent brine were conducted on concrete beams coated with linseed oil emulsions to evaluate its effectiveness as an antiscaling and curing agent. Coated beams showed no loss in 42 day flexural strength over moist-cured controls. Coated beams subjected to 300 freeze-thaw cycles in the presence of water and 2 percent brine were from 4 to 6 times as durable as uncoated beams. Preliminary data indicate that linseed oil may be used as both a curing and antiscaling compound.

D-129 Riley, O., "Development of a Bridge Deck Protective System," Highway Research Record No. 173, pp 13-24, 1967, Highway Research Board.

Waterproofing is the key to prevention of concrete bridge deck deterioration. Coal-tar epoxy resin is the most suitable protective membrane because of its history of satisfactory service, its strength and flexibility, ease of application, and cost. A wearing course is still essential because no membrane is sufficiently wear-resistant. The author suggests a wearing course of dense asphaltic concrete (for impermeability) fortified with asbestos (for stability) and modified with latex (for flexibility). Such a wearing course doubles the cost of the system but increases its service life at least fivefold.

D-130 "Rocket Burner Used in New Hampshire to Repair Frost-Damaged Concrete Pavements," Highway Research Record No. 28, pp 41-44, 1967, Highway Research Board.

Highway maintenance men in New Hampshire have exchanged their jackhammers for "rocket burners" on many repair jobs. The "rocket burners" are cylindrical high velocity air-fuel burners, small enough to be held by hand, that break up and blow out decayed and cracked concrete that must be replaced. Unlike conventional methods that use percussion tools, the burners do not disturb strong concrete and reinforcing steel, and unnecessary cracking of adjacent material is eliminated. The burners were originally developed for surfacing granite.

D-131 Walker, B. J. C., "The Performance of Concrete Roads and Motorways During the Past Decade," Technical Paper PCS 16, 1967, The Concrete Society (London).

Reports results of a condition survey of 89 miles of British concrete pavement up to 10 years old. Performance of these roads confirmed the integrity of the design and construction methods used.

The general conclusion was that no great expenditure is likely on these rigid pavements in the forseeable future. Minor repair work will be required and should be done expeditiously to maintain high performance potentials.

Evaluation of maintenance costs for various pavement types showed that concrete roads could play an ever greater role in Great Britain by providing economical roads producing a greater return from capital investment.

1968

D-132 "Highway Bridge Seat Beam Structurally Restored by Epoxy Crack Injection," New Hampshire Highways, Feb 1968.

A badly cracked concrete bridge seat beam on a New Hampshire highway bridge has been repaired in two days time and at a fraction of the cost of replacement, using Structural Concrete Bonding, a process in which a strong, fast curing epoxy adhesive is injected under pressure into the cracks. The cured adhesive bonds with a strength greater than that of concrete, and effects a permanent structural repair. Article contains equipment and procedures used.

D-133 Byrd, L. G., "Criteria for Maintenance of Multilane Highways," Journal, Highway Division, American Society of Civil Engineers, Vol 94, No. HW 1, Paper 5988, Jun 1968, pp 43-60.

The establishment of proper maintenance standards is a critical and complex challenge to the highway administrator and engineer. Interrelationships exist between the various needs to: protect the highway structure, make optimum use of the available facility, provide safe, convenient, and pleasant service to the user, and make the highway a compatible part of the environment. The criteria established by this report are: outline standards of good maintenance for multilane highways, suggest methods of evaluating maintenance practices and procedures, promote a uniformly high level of maintenance, and foster improvements in the quality and applicability of personnel, equipment, materials, and methods used in maintenance programs. Standards are proposed for four classifications of multilane highways. Standards for physical maintenance are outlined for pavements, structures, guardrail, median barrier, signs, light standards, shoulders, slopes, and drainage systems. Standards for traffic services are outlined for ice control, management of vegetation, litter removal, shoulder and bridge deck cleaning, traffic sign cleaning and renewal, lamp cleaning and replacement, delineator cleaning and replacement, pavement striping and marking and emergency services.

D-134 Ashton, N. L, "New Bridges Founded on Old," Civil Engineering (N.Y.), Vol 38, No. 11, Nov 1968, pp 44-48.

In reconstructing and widening three old bridges, some $2 million was saved by using the original concrete piers and arches. In places the 48 to 62 year old concrete had deteriorated to the consistency of loosely cemented gravel; in other places, it was perfectly sound. The reasons for these variations are told and provide ideas useful to engineers today. Also described are posttensioned rods which were tied around the old piers and posttensioned tendons which tie the parallel arches together at their crowns. Together the posttensioned elements insure that the arches of a span work together.

D-135 Oram, W. C., "Maintenance Practices for Rigid Pavement, Report of Subcommittee on Maintenance of Airfield Pavement," Journal, Aerospace Transport Division, American Society of Civil Engineers, Vol 94, AT1, Nov 1968, pp 57-82.

The Committee on Airfield Pavement has prepared a guide for effective maintenance procedures for rigid pavements. The following maintenance tasks are given detailed coverage: resealing joints, sealing cracks, patching individual spalls, repairing spalled joints, surface patching, full-depth patching, repairing popouts, slabjacking ("mud-jacking"), and temporary repairs. The necessary equipment preparation, materials, and procedures for the above tasks are described and the purpose of each operation is explained. Areas in which special care is required are indicated. The importance of a planned program for timely maintenance to ensure the full, economical service life of concrete airfield pavement is emphasized.

D-136 Corbett, L. V. and Alvey, F. B., "Patching and Grouting of Concrete with Epoxy Systems," Publication SP-21, American Concrete Institute, Paper No. SP 21-6, 1968, pp 37-52.

The general aspects of the use of epoxy compounds and of epoxy curing agents for patching and grouting concrete are discussed. The successful use of epoxy materials requires that certain material criteria are met and that proper surface-preparation procedures are followed. Basic information on both these subjects is presented. This paper describes the application of epoxies for repair of freeze-thaw damage, chert popout failures, damage to precast pieces, and floor deterioration affected by steel-wheel vehicles. Also discussed are prevention of dusting, cavitation, cold joints, and chemical attack.

D-137 Erickson, H. B., "Repair of Cavitation Damage in Concrete with Epoxy Resin Materials," Publication SP-21, American Concrete Institute, Paper No. SP 21-8, 1968, pp 67-78.

Portland-cement concrete in the floor of the outlet works at Fort Randall Dam, Pickstown, South Dakota was damaged by cavitation from high-velocity water flow. An engineering study indicated that repair could be accomplished most economically with epoxy-resin materials. Mix proportions were developed in the Missouri River Division Laboratory of the Corps of Engineers for an epoxy-resin concrete, and epoxy-resin mortar, and an armor coating. The Omaha District office of the Corps of Engineers furnished comprehensive instructions and packaged materials to field personnel for accomplishing the repair at this remote location. The damage was successfully repaired by field personnel having little previous experience with epoxy-resin materials. Herein the materials, mixes, and procedures used are described in detail, including health and safety precautions. An inspection was made after the repaired area had been under water for 5 years, and the repair was found to be performing very satisfactorily. Suggestions for future work of this nature are given.

D-138 Estrada, N. S., "Polyester Overlays for Road and Bridge Protection and Repairs," Highway Research Record No. 242, pp 36-40, 1968, Highway Research Board.

Sealing of deteriorated concrete surfaces and the provision of a new, durable wear surface cannot readily be accomplished through the use of conventional paving materials, such as concrete or asphaltic-concrete. Various synthetic resin systems have been evaluated as sealers and as binders for wear courses in attempting to resolve the problem. Epoxy resin systems have been widely investigated and have the longest history of satisfactory use. This paper described the performance of a system based on polyester resins, over a wide variety of exposures and use conditions. The polyester system is basically quite simple and versatile, involving application of a catalyzed resin to a clean, dry, sand-blasted road surface at a rate of 3 lb/sq yd. Clean, dry round-grain silica is broadcast in excess onto the wet resin. After the resin has cured in 30 to 60 min. the excess sand is brushed off. Three such coats are generally recommended, giving a final thickness of at least 1/4 in. The system cures rapidly over a variety of temperature conditions, 40° to 110° F, so that traffic can be allowed over the surface within an hour after application.

D-139 Gaul, R. W. and Smith, E. D., "Effective and Practical Structural Repair of Cracked Concrete," Publication SP-21, American Concrete Institute, Paper No. SP 21-5, 1968, pp 29-36.

After reviewing briefly why cracks should be repaired, the authors discuss the feasibility of repair, how effective structural repair is accomplished, and limitations of repairs. Examples are given of typical applications of a method which consists of injecting an epoxy-resin adhesive into cracks to "weld" the concrete back together into monolithic form.

D-140 Higgins, G. E. and Peters, C. H., "The Repair of Spalled Concrete Surfaces with Thin Concrete Patches: An Experiment on Trunk Road A.34 at Stafford," RRL Report LR 217, 1968, Road Research Laboratory, Crowthorne, England.

Following earlier experiments in the laboratory and on minor roads, extensive areas of experimental concrete and cement-mortar patches 6 mm (1/4 in.) and 13 mm (1/2 in.) thick were laid in 1959 on a heavily traveled road. Defective concrete was removed by bushhammering process and the repair materials laid both by hand using a vibrating screed and by cement gun.

The condition of the patches after more than 8 years under heavy traffic is excellent and indicates that thin concrete patches provide an effective method of repairing spalled concrete surfaces.

D-141 Kampf, L., "Repair of Concrete Bridge Pavements," Publication SP-21, American Concrete Institute, Paper No. SP 21-7, 1968, pp 53-66.

The mechanism of concrete failure is discussed. Concrete in a bridge deck is subjected to stresses resulting from dimensional changes. There is a shrinkage of the concrete, in the transition from the plastic to the rigid state, when it dries and when the temperature drops. Chemical effects and the freezing and thawing effect can cause expansion. The most difficult stress is caused by vertical deflections. A repair material must therefore withstand these stresses. It must have strength, flexibility, adhesiveness, and a low

susceptibility to temperature change. Epoxies can be formulated to have all these properties. The various materials available for the repair of concrete are discussed as well as the epoxies. The epoxies discussed are straight epoxies, polysulfide and polyamide epoxies, and coal-tar epoxies. Test results are given on these materials and on the effect of formulation on their properties. The use of epoxies as a surface treatment, as an adhesive, and as a binder is discussed. For deep repairs a polysulfide or polyamide adhesive with a high-strength, quick-setting concrete is preferred. For shallow repairs an epoxy mortar is favored. Surface treatments are questionable.

D-142 McElroy, J. A., "Rehabilitation of the Bourne Highway Bridge," Publication SP-21, American Concrete Institute, Paper No. SP 21-9, 1968, pp 79-92.

This paper discusses the various applications of epoxy adhesives and waterproofing materials used to effect a major rehabilitation of the Bourne Highway Bridge which spans the Cape Cod Canal at Bourne, Massachusetts. Discussion concerns the evaluation-of-condition survey to estimate extent of deterioration; preparation of plans and specifications to accomplish repair; phasing of the operations to cause the least amount of disruption to Cape access; and use of epoxy-resin materials to bond old concrete to new, waterproof the concrete deck with a bituminous-epoxy and glass-fabric membrane, and surface-coat concrete and steel. Satisfactory accomplishment of the rehabilitation stresses the fact that utilization of epoxy-resin materials can provide effective and economical repairs and protection to concrete.

D-143 Rooney, H. A., "Epoxies in Concrete Construction and Maintenance," Publication SP-21, American Concrete Institute, Paper No. SP 21-2, 1968, pp 5-8.

This article describes the work done by the Materials and Research Department of the California Division of Highways, since 1954, in adapting epoxy resins to the maintenance and repair of concrete highways and bridge decks. It discusses how the high coefficient of thermal expansion of cured epoxy mortars, which causes portland-cement concrete over

which the epoxy mortars are applied to rupture in tension, may be neutralized by the formulation of epoxy mortars having high creep values at sub-zero temperatures. The first use of adhesives of the epoxy-resin type to bond new portland-cement concrete to old portland-cement concrete was made by the Materials and Research Department in 1954 and is described in this article.

<u>1969</u>

D-144 Williams, E. E., "Summary of Structural Repairs with Epoxy," Presented at the Apr 1969 Structural Engineering Conference, South Atlantic Division, CE.

The purpose of this paper is to outline, briefly, some of the types, uses, and applications of epoxy and is limited to those deemed appropriate for structural application to Civil Works Projects. The sources of information, the applications presented and the contents herein only touch the subject matter and are intended to be used as a springboard to stimulate further discussion and study in consideration of possible applications. The material contained in this paper is a collection of data from a limited source of publications as indicated under the references listed.

D-145 Irwin, R. J. and Corbisiero, J. A., "Protective Coatings for Concrete Bridge Decks: Interim Report," Research Report No. 69-4, Jun 1969, Engineering Research and Development Bureau, N. Y. State Department of Transportation.

Performance of protective coatings for bridge decks is evaluated. Application to bridges on the N. Y. State highway system from 1961 through 1967 included (1) surface overlays, (2) membranes between structural slabs and bitumous wearing course, and (3) surface sealants.

D-146 Ghosh, R. K., Sethi, K. L., and Pant, C. S., "Synthetic Resins for Concrete Repairs," <u>Australian Road Research</u>, Vol 4, No. 1, Sep 1969, pp 50-68.

The laboratory investigation on concrete repairs with particular reference to concrete pavement, using synthetic resin preparations of both polymer and epoxy groups, was reported. Different properties investigated for resin-sand mortars were their compressive, flexural and tensile strengths; their bond with concrete, steel and wood; their resistance to abrasion; and their durability against alternate heating and cooling, and freezing and thawing. The paper also includes details on some field trials and an evaluation of their performances.

D-147 "Grouting Lifts Sagging Pavement," <u>Western Construction</u>, Vol 44, No. 10, Oct 1969.

Depressions in new pavement through Cajon Pass are lifted to within .005 ft of original grade by injections of cement grout under pressure.

D-148 "Concrete Repair Problems. Causes and Cures," <u>Concrete Construction</u>, Vol 14, No. 11, Nov 1969, pp 409-415, 417-421, and 424-427.

Paper deals with studies conducted to determine the causes of deterioration, classification of concrete damage, and recommended repair techniques and selection of repair materials.

D-149 Andrianov, E. G. and Obertenev, V. N., "Protecting Concrete Structures from Corrosion," <u>Coke Chemical</u> (USSR), No. 11, 1969, pp 43-46.

The central Corrosion Research Laboratory at the Zhdanov Coke and Chemical Works has investigated the protection offered by various novel polymer materials and combinations of different materials, including finishes reinforced with fabric interlayers for protecting concrete structures. Coatings with good resistance in all the media investigated can be obtained by combining a priming coat of composition No. 3 (KhSL lacquer modified with polyisobutylene) and top coats of compositions No. 5 (epoxy-coal tar lacquer) and No. 6 (epoxy-"ethinol" lacquer). Coatings based on bitumen modified with

composition No. 3, over a priming coat of composition No. 3 are only resistant in the plant atmosphere. Satisfactory resistance in the plant atmosphere is also obtained by coating with the water-soluble paint KCh-26. Concrete surfaces coated with the 20 percent liquid GKZh-94 emulsion remain water repellent for 4 to 5 mo, but no longer. Chlorsulfonated polyethlene is a very promising material for protecting concrete from attack, but is scarce.

D-150 Spellman, D. L. and Stratfull, R. F., "Chlorides and Bridge Deck Deterioration," Research Report No. M & R 635116-4, 1969, California *Division of Highways.*

As a result of a recent bridge deck study and other related work, a mathematical expression was derived which describes the distribution of chloride in concrete as related to depth below the surface in bridge deck concrete. The validity of the expression is supported by a similar distribution of salt found in piles submerged in bay water. Data are given which shows that the distribution of chloride in concrete is highly variable, and attention must be given to the number of samples when determining the average chloride content.

Steel was removed from one bridge deck and corrosion loss measured. While not structurally significant, the corrosion that had occurred was more than necessary to cause extensive cracking of the concrete.

It was concluded that deck deterioration due to corrosion of the steel could be effectively prevented in new structures by the use of a noncorrosive deicing agent, or the use of an effective sealing membrane to prevent salt intrusion. A membrane placed on a high chloride contaminated deck is likely to accelerate corrosion.

Half-cell potential measurements were made on sections of two bridge decks. They show that corrosion activity of the steel can be nondestructively detected by electrical measurements.

1970

D-151 Givens, J. J. and Carter, G., "Rehabilitation of Offshore Platforms," Civil Engineering (N.Y.), Vol 40, No. 4, Apr 1970, pp 47-49.

The effects of time, corrosion, and violent sea storms on offshore structures have created a need for a rapid and economic system of repair that will not interfere with existing operations. Such a system has been developed. It makes use of prestressing tendons and high-strength, fiber-reinforced concrete.

D-152 Pettitt, R. A., "Bridge Deck Protection and Resurfacing," Journal of the Structural Division, American Society of Civil Engineers, Vol 96, No. ST4, Paper 7217, Apr 1970, pp 791-802.

As a result of the Ohio River Bridge failure at Point Pleasant, West Virginia in 1967, periodic inspections of bridges are requested by The U.S. Bureau of Public Roads. The importance of bridge deck inspection and maintenance was emphasized in a 1964 Highway Research Board Report. The key to extended life of bridge decks, and sometimes to the safety of the entire bridge structure, is found in maintaining the water-tight integrity of the deck. Periodic inspections should logically lead to timely preventive maintenance practices. The history of the Los Alamos Canyon Bridge at Los Alamos, New Mexico, and the continuing investigation of protection materials is used as a typical example of bridge deck inspection and maintenance practices. Protection methods are divided into two categories: (1) Protective coatings for waterproofing the original bridge deck surface; and (2) protective coverings which provide a new wearing surface as well as sealing and waterproofing the deck.

D-153 Cox, F. B., "A Study of the Feasibility of Methods for Increasing the Load-Carrying Capacity of Existing Concrete Beams," Technical Report No. C-70-3, May 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The primary objective of this investigation was to determine the feasibility of increasing the load-carrying capacities of existing reinforced concrete beams by building up their cross sections with additional reinforcement adhesively bonded to their horizontal and/or vertical faces. Waterways Experiment Station correspondence with leading chemical companies indicated that either of several epoxy-resin systems

would provide a bonding strength such that the entire built-up section would act as though it were monolithic; therefore, only two of the most highly recommended systems were tested for their bonding strengths. After the most suitable adhesive (epoxy-resin system) was determined, 14 beams (11 built-up beams with clear spans of 6 ft, and 3 built-up beams with clear spans of 12 ft), excluding the control beams, were cast and tested using additional reinforcement consisting of adhesively bonded steel strips or sheets, precast reinforced concrete panels, or prestressed concrete panels, either singly or in combination. The results of these tests indicated that additional shear and tensile reinforcement can be provided by adhesively bonding these materials or any combination of the materials to the vertical and horizontal faces of the existing members; however, the most suitable and practical method tested was with built-up sections utilizing adhesively bonded precast concrete panels; therefore, it is the procedure most highly recommended at this time. Recommendations are made for the design and fabrication of built-up members, but it should be noted that all conclusions and recommendations were based on short-time static test and could be subject to revision if test data were available on members tested under either sustained or dynamic loading conditions.

D-154 Darroch, J. G. and Furr, H. L., "Bridge Deck Condition Survey," Research Report No. 106-1F, Part 1, May 1970, Texas Transportation Institute, Texas A & M University.

The bridge deck survey reported here was based on a random sample, which ensured an adequate representation of all types of bridges currently in use on highways throughout Texas. The documentation on each bridge included type of construction, age, traffic, location, and other structure-related information. The on-site examination of the bridge deck was done on the basis of individual concrete pours. These were scored with respect to scaling, delamination, cracking, and general deck condition. The results of examining some 5300 bridges, whose decks were made up of about 36,000 separate placing operations, were thus available for summarization. A complete tabulation of the 45 structural characters versus the 13 deck condition items was made.

D-155 Sinno, R. and Furr, H., "Bonded Concrete Overlays," Journal of the Structural Division, American Society of Civil Engineers, Vol 96, No. ST8, Aug 1970, pp 1627-1638.

Repair techniques to protect and rehabilitate deteriorated concrete bridge decks and highway pavements are receiving high priorities by highway departments throughout the United States. Resurfacing concrete with concrete requires investigations of four major study areas: (1) Preparation of existing concrete surface; (2) preparation of new concrete overlay; (3) bonding agents between new and old concrete; and (4) contribution of concrete overlay to the overall behavior of the new cross-section under static and repeated loading conditions. Laboratory tests designed to evaluate the preceding parameters are reported.

Cement grouts and epoxies were used separately as bonding agents on parallel series of tests with preparation of existing surface as a variable. Static direct shear and flexure tests on thin bonded concrete overlays were performed. These tests were used to establish mix designs of overlays and bonding agents, surface preparation requirements, and bond strength between the freshly overlaid concrete and the existing concrete surface. Repeated loading conditions were designed and applied in order to determine the contribution of the bonded concrete overlay to the flexural rigidity and load-carrying capacity of the new cross-section.

The test results have demonstrated that either cement grout or epoxy can be used effectively as bonding agents to make feasible repairs of deteriorated concrete surfaces using thin concrete overlays. Surface preparation was determined to be a key variable in securing a structurally sound bonded overlay.

The performance of precracked, freshly overlaid concrete beams was evaluated under static and repeated loading conditions. Over 2,000,000 cycles of primarily compressive stresses in the overlay, within the working range, were applied. No bond failure of grouted or epoxied concrete overlays was detected. The thin-bonded concrete overlays increased considerably the flexural rigidity and the load-carrying capacity of the tested beams. By the end of the repeated loading cycle the decrease in the flexural rigidity was small and within the expected bounds of a structurally sound concrete structure.

D-156 Lilley, A. A., "Methods of Repairing and Maintaining Concrete Roads," Dec 1970, International Road Federation.

The methods of repair and maintenance examined include: reinstatement of trenches, widening and realignment, resealing of joints, repair of spalled joints, repair of cracks, repair of scaled surfaces with thin bonded toppings, and resurfacing.

D-157 Moraldi, G., "Surface Repairs on Concrete Pavements," Dec 1970, International Road Federation.

Laboratory tests and field installations are being used in the investigation of various methods of repairing concrete pavements of airports. The freeze-thaw test and observations of field behavior are used to study the adhesion and performance of thin epoxy resin surface patches. Plain and reinforced concrete overlays with and without admixtures in thicknesses of 1 to 3 in. were used for repairing the pavements. For some installations, an insulated layer will be placed on the old concrete to break the bond between the old concrete and the overlay. These tests should determine the best materials for repairing concrete pavements and for extending the life of the pavement and maintaining it in the best possible condition.

D-158 Brewer, R. A., "Epoxy-Asphalt Open-Graded Pavement as a Skid-Resistance Treatment on the San Francisco Bay Bridge," Highway Research Board Special Report No. 116, 1970, pp 42-47.

In late 1969, the Division of Bay Toll Crossing applied 1/2-in. thick epoxy-asphalt, open-graded pavement to 2 large test areas on the heavily traveled San Francisco-Oakland Bay Bridge. Two types of aggregate, air-cooled iron slag and granite, were used with 1/4-in. California standard open grading. This report describes the selection of epoxy asphalt as the skid-resistant treatment, its application, and its performance to date. In the 11 months since its application, the pavement has been tested for skid resistance and core pullout strength. In spite of minor localized raveling attributed to inadequate compaction in isolated areas due to

cold temperatures at the time of placing and to other factors, the pavement promises fulfillment of the purpose for which it was selected: to provide increased skid and hydroplaning resistance, low increase in dead loads, and superior structural properties. The accident history has improved substantially in the resurfaced areas.

D-159 Ghosh, R. K., "Concrete Repairs with Epoxy and Polyester Resins," Highway Research Record No. 327, pp 12-17, 1970, Highway Research Board.

The Central Road Research Institute, New Delhi, conducted laboratory investigation and field trials with heat-convertible synthetic resins such as epoxy and polyester resins to determine their efficacy in concrete repairs with particular reference to concrete pavement. Although both of these resins, particularly the epoxy resin, have been in use for concrete repairs for some time, more information is needed to establish satisfactorily their different engineering properties in relation to environmental and job conditions.

1971

D-160 "Cracked Concrete Pilings Repaired with Epoxy Adhesive for Large Savings," World Construction, Mar 1971.

Cracks in six precast, prestressed concrete pilings were repaired with a structural concrete bonding process in six working days at a cost of $1800. Normal cost for scrapping and replacing the pilings would have been approximately $18,000.

D-161 Garfield, H. G., "Epoxy Injections Repair Historic Prestressed Concrete Bridge," Civil Engineering (New York), Vol 41, No. 3, May 1971, pp 39-41.

Inspection of Philadelphia's Walnut Lane Memorial Bridge, reported to be the first post-tensioned prestressed concrete bridge in the United States, revealed cracking. The cracks

were repaired by pumping epoxy into the cracks, using an unusual procedure that combines the epoxy components in a special mixing head prior to its injection into a crack.

D-162 Green, J. K. and Long, W. B., "Gunite Repairs to Fire-Damaged Concrete Structures," Concrete (London), Vol 5, No. 4, Apr 1971, pp 118-122.

The use of concrete placed by cement gun as method that may be used to repair concrete structures damaged by fire is discussed. Information on the effects of heat on the engineering properties of concrete and reinforcement, on estimating the peak temperature attained during the fire and classifying the degree of repair necessary and on current practice and recommended procedures for carrying out repairs with gunite.

D-163 "Underwater Pier Inspection," Railway Track and Structures, May 1971, p 28.

Procedures explained for inspection of underwater sections of railway bridge piers at Rankin, Pennsylvania; structures include mortared rock; seriously deteriorated mortar joints caulked and grouted using fly ash cement and No. 5 Embeco grout to minimize shrinkage.

D-164 Aaron, F., "Atlanta Contractor Finds Efficient Way for Cleaning Concrete and Brick Stains," The Dixie Contractor, Jun 25, 1971, p 46.

A. R. Winter Company, Inc., Atlanta, uses Omega 1000 Concrete Cleaning Unit, built by Superior Manufacturing Company, with 801 Super Real Clean Chemical Cleaner solution and finds he eliminates up to 90 percent hand cleaning, both concrete and brick.

D-165 "44-Year-Old Bridge gets New Deck After Checkup," Engineering News-Record, Jun 27, 1971, p 14.

Peace River Bridge, Niagra River, New York, has 3 lanes of granite block wearing surface laid in 1926 removed to concrete deck. Inspectors sounded concrete for faulty spots; contractor to waterproof slab after repair and installation of new expansion joints, cover with 1.5 in. of asphaltic concrete, 1 in. asphaltic asbestos.

D-166 Fuller, J. D. and Kriegh, J. D., "Maintenance and Repair of Concrete and Masonry Structures: Epoxy Pressure Grouting," NTIS Publication AD-734 930, Jul 1971, U.S. Department of Commerce, Springfield, Va.

Existing and revised methods used for pressure grouting cracked concrete and masonry were studied. Hand gun and pressure tank grout-injecting equipment were studied as well as epoxy resin grouts. Job site visitations, laboratory, and controlled field tests were used as mechanisms to perform the evaluations.

As a result of studying existing grouting techniques, materials and methods were selected for use in the laboratory and field. The best characteristics of several grouting methods were combined to develop a new technique. Grouting materials were selected on the basis of viscosity and bonding capabilities. Three systems were used for study.

Field studies led to personal evaluation of equipment and techniques as well as to physical evaluation of depth of penetration and effectiveness of repair. Laboratory studies led to curves providing an estimate of flow rate of a grout within a given crack width as a function of grout viscosity.

Finally, a 'Guide for Pressure Grouting Cracked Concrete and Masonry Structures with Epoxy Resins' was prepared.

D-167 "Leaky Underpasses at Mansfield, Mass., Made Watertight," New England Construction, Jul 19, 1971, p 34.

Voids under underpass pavement force water onto highway surface. Massachusetts Department of Public Works' Mansfield staff solves problems by drilling 2-1/2-in. holes in pavement, pumping cement mortar grout into voids to provide watertight barrier.

D-168 "Contractor Begins Repair Work on San Francisco Water Tunnel," Engineering News-Record, Jul 22, 1971, p 12.

Lockheed Shipbuilding and Construction begins repair of San Fernando, California, water supply tunnel damaged by an explosion. The structure has precast concrete lined segments.

D-169 Lal, S. M., "Repair of Earthquake-Damaged Buildings," Building Research, Jul-Sep 1971.

Presents observations relating to structural damages in buildings due to earthquake shocks and gives brief instruction on repairs. Structures are grouped in three categories, including reinforced concrete. Concrete repair methods include bandages, routing and sealing, stitching, grouting.

D-170 Spellman, D. L., Woodstrom, J. H., and Neal, B. F., "Investigation of Unbonded PCC Overlays," Report No. M/R-635165, Sep 1971, California State Division of Highways, Materials and Research Department.

An investigation of unbonded PCC overlays placed over old PCC pavements is reported. Test sections were constructed to compare the effect of various materials as bond breakers. Performance was measured by the ability of the overlay system to prevent reflective cracking. It was concluded from these tests that an asphalt, such as MC-250, with a light sand cover to prevent pickup, reduces bond sufficiently to prevent reflective cracking, even when joint spacing is different from that of the base pavement. Wax base curing compound, specified as a bond breaker on one project, did not

perform as well as anticipated. At a considerably higher cost, asphalt concrete also performs very well and is particularly worth consideration when leveling of the base pavement is necessary.

D-171 Boulware, R. L. and Elliott, A. L., "California Seals Salt-Damaged Bridge Decks," Civil Engineering (N. Y.), Oct 1971, pp 42-44.

California's Division of Highways tests several bridge deck sealants searching for ellusive non-corrosive deicing material. Approach is to seal deck to protect it from corrosive salt brine and while perfect seal is yet to be found, several, including emulsified coal tar and a thermo-plastic sheet system, extend the bridge deck's life in heavy salting areas.

D-172 Branson, R. E., "The Case for Proper Membrane Waterproofing," The Construction Specifier, Oct 1971, pp 50-52.

There is frequently a fuzzy distinction between dampproofing and membrane waterproofing when selection of materials is being made for structural foundations. True waterproofing membranes are generally elastometric type or hot mopped. Importance of surface preparation, bond to substrate, installation safety and cleanliness stressed and common installation errors itemized.

D-173 Hagenbuch, J. J., "Bay State Considers Alternative Bridge Deck Repairs," Public Works, Oct 1971, pp 68-69, and 104.

Deterioration of concrete bridge decks discussed by structures maintenance engineer who reports 30 percent of bridge maintenance funds in Massachusetts are expended on decks. Historical practices cited, plus alternatives, including dusting of cement applied to waterproofing membranes and elastomeric waterproofing barriers applied to concrete.

D-174 Comstock, C. F., "Inspect Bridges Now, Avoid Problems Later," Civil Engineering (N.Y.), Vol 41, No. 11, Nov 1971, pp 66-67.

Dangerous bridge conditions that might eventually lead to collapse can be avoided or repaired if bridges are inspected regularly and thoroughly. This article offers guidelines for good bridge-inspection procedures, and examines the consequences of neglecting repairs.

D-175 Elliott, R. P., "Thickness Design Procedure for Bituminous Resurfacing of Portland Cement Concrete Pavements," Nov 1971, Illinois State Division of Highways, Springfield, Ill.

Performances of 89 resurfaced PCC pavements analyzed, compared to performance expected from new rigid, and flexible pavements. Findings led to resurfacing design procedure based on modification of Illinois' current rigid pavement design procedure.

D-176 "Polyethylene Pipe Inserted into Deteriorating Sewer Line," Water and Sewage Works, Nov 1971, pp 370-371.

Twelve-in. polyethylene pipe inserted into about 4,000 ft of hydrogen sulfide damaged concrete pipe at Pasadena, Texas, at cost of about $16 per foot. Rehabilitation of line cost less using plastic pipe, eliminated traffic and public relations problems.

D-177 "Improving Pavement and Bridge Deck Performance," 1971, Highway Research Board.

Proceedings of Western Summer Meeting of Highway Research Board and California Division of Highways, August 1970, identifies causes of premature failures of pavement structures and of abnormally high pavement disintegration rates, suggesting possible solutions. Includes examination of concrete bridge deck deterioration.

D-178 "Maintenance Operations and Applied Systems Engineering," Highway Research Record No. 359, 1971, Highway Research Board.

Eight reports, covering use of economic theory, statistics, operations research, systems techniques in planning and managing highway maintenance.

1972

D-179 Byrd, L. G., "Innovative Highway Maintenance Techniques," Public Works, Feb 1972, pp 46-48.

Outlines activities, principle elements or subdivisions of activities, techniques, methods for roadway shoulder and bridge deck maintenance for various materials, including concrete. Calls on maintenance personnel to analyze work, environment requirements, equipment, before getting underway.

D-180 "Steel Fiber Reinforced Concrete Overlays Installed on Airport Taxiway," American Concrete Paving Association Newsletter, Mar 1972.

Progress report on restoration of 30-year-old runway at Tampa, Florida, International Airport; project includes experimental work. Steel fiber reinforced concrete on trial mix combines fly ash and needle-like steel fibers in relatively large quantities for 6- and 4-in. test sections 75 ft and 175 ft long. Designers contend that supplementing the 5-1/2 bags of cement with fly ash produces the equivalent of a nine-bag mix.

D-181 Zitelli, J. P., "Developments in the Maintenance of Structures," Public Works, Apr 1972, pp 56-58 and 88.

Summarizes joint, deck, leakage repair practices of Port Authority of New York.

D-182 Borden, R. C. and Selander, C. E., "Application of Epoxy Resins in Tunnel Lining Concrete Repair," Journal of the Construction Division, American Society of Civil Engineers, Vol 98, No. CO2, Paper 9180, Sep 1972, pp 161-172.

Concrete lining in a large diameter tunnel spillway damaged by cavitation erosion caused by variable high flows up to 20,000 cfs was repaired by use of bonded concrete, and epoxy bonded epoxy mortar. Epoxy bonded epoxy mortar was used to make the repairs except in the damaged areas of large volume. The repair area to receive epoxy mortar was prepared by bushhammering, chipping, or sandblasting. The surfaces of the concrete were made completely dry. Seeping hairline cracks were rendered dry by chemical grouting. Air and concrete temperature was maintained at about $60^{\circ}F$ by a heating system. A clear epoxy bond coat was applied to a small area of prepared concrete surface. Epoxy mortar was applied to the bond coat while the bond coat was in a fluid to tacky condition. Curing and post curing of the epoxy mortar by use of propane infrared heaters and heat lamps were required. Painting of the cured mortar with an epoxy phenolic paint was specified.

D-183 "Earthquake Repairs," Aqueduct News, Metropolitan Water District of Southern California, Sep 1972, p 3.

MWD engineers design methods to repair badly damaged reservoir at Joseph Jensen facility, San Fernando Valley, California. Epoxy bonding agents featured for smaller cracks.

D-184 Emmerling, C., "Montana Power Company's Dam Repair Program," Journal of the Construction Division, American Society of Civil Engineers, Vol 98, No. CO2, Paper 9208, Sep 1972, pp 295-311.

Value of Federal Power Commission's consultant safety inspection program for dams demonstrated by findings, recommendations, and remedial measures taken as result of inspection of one project with nine dams on Missouri and Madison Rivers in Montana. Drawings, tables, photographs illustrate nature and details of work accomplished in improving stability and safety of those structures.

D-185 Parker, F., Jr., "Construction of Fibrous Reinforced Concrete Overlay Test Slabs, Tampa International Airport, Florida," Project FAA-082-420-014, Oct 1972.

The report describes the planning and construction of two fibrous reinforced concrete overlay test sections at TIA. The test sections include 4- and 6-in.-thick overlays located on a currently used parallel taxiway to one of the primary N-S runways. The test sections were inspected after about one month's traffic, and the condition of the overlays is described herein. Conclusions based on the construction of the test section indicate that fibrous reinforced concrete can be produced in a central mix plant and placed with a slip-form paver. Procedures and equipment for bulk handling of the fibers will have to be developed.

D-186 "Bridge Deck Gets Thin Concrete Overlay," Better Roads, Vol 42, No. 11, Nov 1972, pp 14-16.

Methods of resurfacing a bridge deck on a main traffic artery in Detroit, Michigan which normally accommodates a two-way traffic flow of 154,000 vehicles a day are outlined. The system for the resurfacing operation consisted of a self-propelled, continuous mixing machine with a designed capacity of approximately 10 cu yd per load and a self-propelled finishing machine.

D-187 "Studies on Repair Techniques of Cement Concrete Pavements," 1972, Clinic of Scientific and Industrial Research (India).

An investigation is made into the effect of varying proportions of curing agent on the compressive strength, air voids and pot life of synthetic resins.

1973

D-188 Burchett, K. R., "Concrete Repair at Norfolk Cultural and Convention Center," Proceedings, American Concrete Institute, Journal, Vol 70, No. 1, Jan 1973.

Describes the planning and execution of repair work on structural/architectural concrete at Norfolk Cultural and Convention Center, Virginia. The repair had to match color and texture of surrounding concrete as well as provide structural integrity for buttresses supporting a large dome. The repair work was accomplished while construction of the facility continued without delay.

D-189 Fuller, J. D. and Kriegh, J. D., "Guide for Pressure Grouting Cracked Concrete and Masonry Structures with Epoxy Resins," Appendix to Technical Report No. M-9, Feb 1973, U. S. Army Construction Engineering Laboratory, Champaign, Ill.

This report serves as a guide for the purchase, performance, and use of materials by personnel engaged in the maintenance and repair of cracks in concrete and masonry structures, and to aid in: (a) proper selection and employment of appropriate materials, equipment, and practices, (b) competent inspection and evaluation of the work done, and (c) use of proper safety precautions.

The text covers both technical discussion and application procedures to aid the engineer in making decisions whether or not to pressure grout and, if so, by what method. An appendix gives detailed grouting procedure for individuals performing the work.

D-190 Kemphues, R. F., "Materials and Procedures for the Repair of Spalls in Concrete," Technical Report M-40, Mar 1973, U. S. Army Construction Engineering Research Laboratory.

Old and new materials used for repairing damaged or deteriorated concrete are studied and evaluated. Large damaged areas can be successfully and economically repaired using a good-quality, low-slump portland cement concrete bonded to the old concrete with an epoxy resin grout. Small spalls and specialized areas can best be repaired with an epoxy resin mortar. Surface preparation must be completed and manufacturer's directions for mixing and curing followed. Expansive cements and new modified latex materials show promise, but field data are insufficient to draw conclusions.

D-191 Arnold, C. J. and Brown, M. G., "Experimental Steel-Fiber-Reinforced Concrete Overlay," Apr 1973, Michigan Department of State Highways.

A jointed fibrous concrete overlay of 3-in. minimum thickness was mixed and placed with a conventional batch plant and slipform paver with only minor alterations in procedure. Fiber contents were 120 and 200 lb per cu yd of concrete. Joint spacings in the overlay were 50 and 100 ft. The fibrous concrete was handled quite well by the construction equipment, with the main problem being formation of small fiber balls in the mix.

The new pavement was opened to heavy traffic after only two days cure at quite cold temperatures. Early performance has been poor in the areas with 120 lb of fibers per cu yd, but considerably better in the 200-lb sections. This is particularly true on the two outside, most southerly, lanes.

D-192 "Concrete Roads - Maintenance and Repair," Highways and Road Construction, Vol 41, Jun 1973, p 19.

Work done in 1972 on concrete pavement originally laid in 1958. Some rehabilitation had been done in the 1960's, but the cement and resin-bonded materials then used had deteriorated. Defective concrete was removed, mostly by use of Klarcrete machines. The machine is programmed to cut a specific depth and area. Maximum depth of cut is 4 in. but 1 in. is usually sufficient to reach sound concrete in spalled areas. Different materials were used to patch the pavement, including epoxy resin. Larger repairs were rapid hardening cement concrete. Twenty hours was the maximum time traffic kept off an area.

D-193 Biviridge, R. L. W., "Repairs and Extensions to Concrete Structures Using Resin Anchored Bars," Civil Engineering and Public Works Review, Vol 68, No. 804, Jul 1973, pp 609-615 and 617.

The article outlines the use of encapsulated polyester resins for bonding steel to concrete in practical situations and shows the range of work for which they can be used.

D-194 Kern, E., "Sealing of Cracks in Concrete (Dichten von Rissen im Beton)," Betonwerk und Fertigteil-Technik (Wiesbaden), Vol 39, No. 7, Jul 1973, pp 510-516.

The main causes of cracking in concrete are briefly discussed. Two methods for sealing the cracks with epoxy resin, injection and brush application, are described.

Recommendations are given for the selection of suitable resins. Tests performed on drilled cores showed that injected cracks are force-locking. The depth of penetration of the resin by brush application is, in most cases, sufficient for watertight sealing of the cracks and protecting reinforcement against corrosion.

Sealing of concrete in case of penetrating moisture is also described.

D-195 Sawyer, R. G., Boyko, L. L, and Hunt, G. M., "Microwave Heating for Maintenance," SURC TR-73-436, Aug 1973, Syracuse University Research Corporation.

A microwave approach to polymer concrete curing has evolved into a program to develop a quick-patch technique for bridge decks and railways. Most polyester resins used in this program are of the unpromoted type; even if the resin is mixed with a catalyst, it will not self-cure. The patch material can be mixed at the beginning of a work shift and remain uncured throughout the day and until it is cured with microwave energy. In most instances, standard highway aggregates can be used, once they have been sieved to pass a No. 5 mesh screen. Once the polymer concrete is tamped into the hole to be patched it is irradiated with microwave energy. The research team is able to fill a void in a concrete section and completely cure the patch in less than 3 minutes.

D-196 ACI Committee 503, "Use of Epoxy Compounds with Concrete," Proceedings, American Concrete Institute, Journal, Vol 70, No. 9, Sep 1973.

Epoxy compounds have found a wide variety of uses in the concrete industry as coatings, grouts, binders, sealants, bonding agents, patching materials, and general adhesives.

Properties, uses, preparations, mixtures, application, and handling requirements of epoxy resin systems when applied to and used with concrete and mortar are presented. The adhesiveness of epoxy and its chemical, thermal, and physical properties are given. The modification of the foregoing properties to accommodate given situations is reviewed.

Problems encountered in surface preparation are reviewed and procedures and techniques given to insure successful bonding of the epoxy to the other materials. Temperature conditioning of the base material and epoxy compound are outlined. The cleaning and maintaining of equipment is reviewed. Procedures to be followed in the application of epoxy compounds in the several use situations are given. The important factors which insure that the epoxy compound will harden (cure) and therefore perform its function are discussed together with alterations of the hardening rate. The allergenic and toxic nature of epoxies and the chemicals used with them in the industry create a hazard and precautions are detailed throughout the report.

D-197 Doble, D. H., "Maintenance and Repair of Ancillary Equipment," Proceedings, Engineering Foundation Conference; Inspection, Maintenance, and Rehabilitation of Old Dams, Sep 1973.

This paper describes examinations to ancillary equipment of various dams under the control of the Sacramento District Corps of Engineers. Two problem areas are covered: (1) conduit erosion and cavitation damage to slide gates and (2) settlement of bridge abutments. Various methods of repair to the conduit and slide gates were tried and their effectiveness has been monitored yearly.

D-198 "Inspection, Maintenance, and Rehabilitation of Old Dams," Proceedings, Engineering Foundation Conference, Pacific Grove, Calif., 23-28 Sep 1973.

The value of Engineering Foundation Conferences, where a knowledgeable, concerned, and involved group meet for a week's discussion, generally informally, of a timely topic has been

demonstrated by the many conferences held in the past 12 years. Frank, off-the-record discussions are of special importance in exploring all aspects of a problem.

In September 1973, nearly 200 conferees spent five days at the Asilomar Conference Grounds, Pacific Grove, California, discussing the inspection, maintenance, and rehabilitation of old dams. Representatives of Government entities, Federal, state, and local; along with consulting firm, public utility and academic participants explored the various problems in depth. Design and construction engineers, hydrologists, geologists, and other specialists involved with programs related to design, construction, and operation of dams reviewed existing programs and case histories, and examined results.

The result is a group of papers that can be considered a good "state-of-the-art." Supported by the unanimous vote of the conference, decision was made to publish the proceedings to make the information available for reference and use in the developing, comprehensive program of safety of dams getting underway nationwide. This publication is the result.

D-199 Stamm, G. R., "Rehabilitation of Dams: Retrospect and Prospect," Proceedings, Engineering Foundation Conference; Inspection, Maintenance, and Rehabilitation of Old Dams, Sep 1973.

This paper describes the importance of continuing inspection of dams to monitor stress, stability, strength, and safety characteristics. Consideration should be given to the overall importance of the reservoir operation as well as the dam structure itself. The author outlines present practices of repair and discusses the impact of new technology in materials for repair. He also discusses the role of research in developing new methods of rehabilitation of old dams.

D-200 "Concrete Repairs Made Easier," California Builder and Engineer, Vol 79, Oct 12, 1973, pp 60 and 62.

A wide variety of exotic and unique materials have recently been made available to simplify the bonding, protecting, resurfacing, and repairing of highways and other concrete surfaces. Adhesives placed full-depth completely seal cracks

and fissures. New coatings effectively stop water seepage and resist weathering. Bonding systems enable resurfacing to adhere permanently to old or damaged paving. Examples and location of each are given.

D-201 Dallaire, G., "Halting Deck Deterioration on Existing Bridges," Civil Engineering (N. Y.), American Society of Civil Engineers, Oct 1973, pp 80-86.

Many reinforced concrete bridge decks across the United States may be headed for rapid deterioration. The concentration of chloride ion in the concrete may be steadily increasing as a result of deck salting. If the concentration of the chloride ion exceeds 2.0 lb/cu yd at the top layer of reinforcing steel, then corrosion of these reinforcing bars is highly probable. But if the deck's chloride ion content is below 0.5 lb/cu yd, corrosion should not occur. These decks should be covered with an impermeable membrane and an asphaltic concrete overlay. California and some other states use three tools for determination of the condition of a deck: dragging a chain over the deck to indicate the presence of subsurface fractures (delamination); halfcell potential measurements, which indicate active corrosion in reinforcing bars; and taking concrete core samples from the deck and analyzing them for chloride concentration. A promising solution for these badly deteriorated decks is cathodic protection, the imposition of a voltage on the deck that stops ongoing corrosion.

D-202 "How Cracking is Controlled," Concrete Construction, Nov 1973, pp 517-520.

Paper covers understanding cracking - drying shrinkage - thermal contraction and expansion - cracking from loading and usage - how to predict cracking in floors on grade - what joints should do for a slab - kinds of joints - load tranfer at joints in floors on grade - notes on joint construction - use of steel for crack distribution.

D-203 Martin, R., "Design Considerations for Resurfacing Pavements with Concrete," Highway Research Record No. 434, pp 24-32, 1973, Highway Research Board.

The most common methods for determining concrete resurfacing thickness are reviewed, and the major factors affecting the design of concrete resurfacing are discussed. It is suggested that limitation of slab deflection is of great importance. Deflection at joints, cracks, and free edges is greater than deflection at some distance from those discontinuities. Based on laboratory data, maximum slab deflection for various methods of load tranfer across joints or cracks is proposed. The methods of load transfer discussed are aggregate-interlock, dowels, and continuous reinforcement. The effect of load position and method of load transfer on slab deflection is noted, and the structural benefit of tied concrete shoulders is indicated. Values for the slab support capacity of subgrades, subbases, and existing pavements are suggested, and, based on concrete pavement performance at the AASHO Road Test, maximum allowable slab deflection was calculated to be 0.025 in. Equating slab depths determined by calculation and field performance made it possible to establish a relation between static loads and truck traffic. Concrete resurfacing thickness was then related to truck traffic, method of load transfer across transverse joints or cracks, shoulder type, and slab support. A design example is used to illustrate how concrete resurfacing thickness may be determined. The design and performance of some recent concrete resurfacing projects are considered.

D-204 Pinkham, C. W., "A Review of the Repair of Two Concrete Buildings Damaged by the San Fernando Earthquake," Proceedings, American Concrete Institute, Journal, Vol 70, No. 3, Mar 1973.

The San Fernando Earthquake damaged many buildings which have been described in many reports. Some of the buildings were damaged to the extent that direct repair of the structures was not economically feasible. Most buildings could be repaired to provide as good or better protection against future earthquakes as existed just prior to the Feb 9, 1971, earthquake. The repair of two such buildings are described in the paper. Both the Indian Hills Medical Center, and the Republic Insurance Company Building, used epoxies to seal cracks in the shear walls, and had some additional walls provided using pneumatically applied concrete.

The location, building construction, description of possible severity of shaking, and the amount of damage incurred, are described. The location of each building with respect to the epicenter of the earthquake is discussed. The general construction of the buildings are discussed with particular

reference to the lateral force resisting system. A discussion of the possible severity of shaking at the time of the earthquake is given. The areas of major damage are discussed to give an idea of the amount of repair that was required.

The experience gained by the repair of these buildings has emphasized some of the problems that need to be overcome by the engineer. These are pointed out in the hope that interest will be generated to solve some of the basic unknowns faced by the design engineer.

D-205 Warner, J., "Restoration of Earthquake Damaged Concrete and Masonry," Paper presented at the Fifth World Conference on Earthquake Engineering, Rome, 1973.

Several unique methods have been used to restore earthquake damaged concrete and masonry structures in Southern California. Involved are pressure injection of various grout materials into structural cracks and voids. Case histories are presented as is a discussion of the original research and testing evaluation of the various systems which included expansive cement grout, low viscosity epoxy, polyester resin and polyurathane and epoxy-ceramic foam materials.

<u>1974</u>

D-206 Foor, B. C., "An Operational Report on Prefabricated Pavement Sections for PCC Pavement Repairs," Feb 1974, Caltrans.

This paper describes repair to a section of the Ventura Freeway. It became necessary to replace the entire section of traffic lane and, rather than accepting the 7 to 10 day delay normally required for the cure of fresh concrete, an election was made to use prefabricated pavement sections laid over a grout base.

D-207 "Precast Slabs Speed Road Repairs," <u>The American City</u>, Vol 89, Feb 1973, p 40.

For three years the Michigan State Highway Department has been developing highway repair procedures using precast concrete slabs. The slab sections are formed and cast in specified sizes rather than casting one large slab and then cutting it. The slabs are all 12 ft in width but the thickness varies, depending on the pavement to be repaired. Four standard lengths have been established - 6, 8, 10, and 11 ft. The big disadvantage listed is the cost.

D-208 Stanivuković, B. and Knezević-Vuksanović, N., "Contribution to the Possibility of Using Synthetic Resins in Reinforced Concrete Bridge Repair," <u>Nase Gradjevinarstvo</u> (Beograd), Vol 28, No. 3, Mar 1974, pp 18-21.

A reinforced concrete overpass with the quality of the pavement concrete much below the required quality was repaired by strengthening the low quality pavement with a new layer of reinforced concrete. A synthetic resin coating achieved good bonding between the two concretes as confirmed by adequate tests along the cross section.

D-209 Bell, R. A., "Shotcrete Restoration of a Historic Landmark," <u>Concrete Construction</u>, Vol 19, No. 4, Apr 1974, pp 161-163.

Reports the repair and shotcrete resurfacing of a 65-year-old historic landmark. Designed by Frank Lloyd Wright, the Unity Temple in Oak Park, Illinois, is an example of early and innovative use of reinforced concrete. The architects and contractors involved in the project used pneumatically applied pea gravel concrete coating to restore the structure.

D-210 Pike, R. G., and Baker, W. M., "Concrete Patching Materials," Report No. FHWA-RD-74-75, Apr 1974, Federal Highway Administration.

Nine potential patching materials were evaluated by a series of different tests and compared with a Type III High Early cement to determine which tests would be most significant and which of the nine materials showed sufficient promise to warrant further evaluation by field installations.

The following six tests appear to evaluate the most significant properties of a patching material: (1) Initial setting time; (2) Compressive strength; (3) Bond strength; (4) Resistance to scaling; (5) Resistance to rapid freezing in air and thawing in water; (6) Percentage of chlorides in the mortar.

It is impossible to fully evaluate the performance of the various materials without knowing the method of application and how they will actually be used. Therefore, it is recommended that those materials which appear promising be tested in the field.

D-211 Simonsen, J. E., "Concrete Pavement Replaced in 1-1/2 Hours," Civil Engineering (N. Y.), American Society of Civil Engineers, Vol 44, No. 4, Apr 1974, pp 62-64.

In order to find a lasting concrete pavement repair that would reduce lane closure time to a minimum, Michigan has developed two procedures to date: precast slab repairs, and repairs with fast-setting concrete. A previously sawed 10- by 12-ft concrete area can be removed, replaced with a precast slab, and opened to traffic in approximately 1-1/2 hr. A repair with fast-setting concrete can be subjected to traffic about 6 hr after placing. The limits of the failed area are sawed full depth and the concrete is removed without disturbing the existing base. Joints between the old and new slab may be doweled or undoweled, and can be either contraction or expansion joints. Evaluation to date indicates that the repairs are performing satisfactorily.

D-212 Berry, N. K., "Repairs of the Construction Irregularities in the Finished Concrete Surface of the Beas Diversion Tunnels," Indian Concrete Journal (Bombay), Vol 48, No. 5, May 1974, pp 146-149.

Deals briefly with the delayed repairs carried out in the 4774-m length of the five Beas diversion tunnels before the actual diversion of the river waters through them. The reasons for adopting epoxy repairs are discussed and brief details are given of the testing and the method of application of the epoxy resins.

D-213 Canovas, M. F., "Repairs and Strengthening of Concrete Structures Using Epoxy Resins," Revista Del IDIEM (Santiago), Vol 13, No. 1, May 1974, pp 1-22.

Epoxy resins can be used with advantage to repair and strengthen reinforced concrete structures. They are suitable for sealing concrete fissures and cracks to ascertain monolithic bonding in concrete construction joints, and to repair and strengthen reinforced concrete columns and beams. For each of these cases, details are given of recommended procedures and examples are presented of successful actual applications of epoxy resins.

D-214 Galler, S. and Steinberg, M., "Polymer Concrete Shows Promise as Patching Material," Public Works, Vol 105, No. 5, May 1974, pp 92-93.

A report on experiments made by the New York City Transportation Administration on use of polymer concrete for full-depth patches. Repaired sections were reopened to traffic in about one hour.

D-215 Crozier, A. C., "Strengthening a Fifty-Year-Old Viaduct," Concrete (London), Vol 8, No. 7, Jul 1974, pp 22-25.

The reinforced concrete viaduct built in 1926 has stood without significant maintenance or any modification and met the continuous live load demands made upon it by the cement works traffic. Currently, the coal and gypsum traffic inwards and cement traffic outwards is at total volume of approximately 6300 tons, or 40 loaded trains, a week. At a comparatively low cost, the viaduct was repaired and strengthened to carry the higher loads expected, and it is expected that the structure will continue to give good maintenance-free service for many years to come. Details of the repair work are given.

D-216 Mehta, H. C., Chen, W. F., Manson, J. A., and Vanderhoff, J. W., "Innovations in Impregnation Techniques for Highway Concrete," Report No. 390.8, Jul 1974, Fritz Engineering Laboratory, LeHigh

University, Bethlehem, Pa.; also Transportation Research Record No. 542, pp 29-40, 1975, Transportation Research Board.

Describes some successful preliminary experiments with two possible new approaches to the problem of deterioration of concrete bridge slabs, as well as reduced skid resistance and unacceptable wear rates of their surfaces. The use of a pressure-mat technique for impregnation with organic and other materials, and the use of sulfur as an impregnant are discussed as possible means for improving and simplifying the overall process, with consequent reductions in time and cost.

The authors conclude that both approaches show excellent promise for economizing, simplifying, and rationalizing the laboratory-field techniques developed so far. Further work is continued in this area as the approaches show promise of easy adaption for the large scale impregnation of bridge decks, highways, and airfield runways.

D-217 Stratton, F. W. and McCollam, B. F., "Repair of Hollow or Softened Areas in Bridge Decks by Rebonding with Injected Epoxy Resin or Other Polymers," Report K-F-72-5, Jul 1974, Kansas State Highway Commission.

The objective of this project was to develop a repair technique for bridge deck delaminations which could be used by highway maintenance personnel. The technique was to consist of injection of epoxy resin into the deteriorated areas to bond them back into one monolithic form with strength equal to or greater than the original deck. Equipment has been developed which makes the injection of epoxy into bridge deck delaminations (hollow planes) practical. Four concrete crack grouting epoxies have been laboratory and field tested.

D-218 "On the Santa Fe - Epoxies Restore Cracked Concrete," Railway Track and Structures, New York, Vol 70, No. 9, Sep 1974, pp 40-42.

The use of epoxies to knit together concrete structures that have developed structural cracks has been adopted as a regular practice by the Santa Fe. Defects are sealed with epoxy paste and bonding formulation is pumped into voids. Four main steps are outlined.

D-219 Smith, D. J., Jr., "Repair of Earthquake Damaged Underground Reservoir," Journal of the Construction Division, American Society of Civil Engineers, Vol 100, No. CO3, Sep 1974, pp 449-468.

A concrete underground water storage reservoir, damaged by earthquake, was repaired with epoxy compounds and by employing some unusual construction methods. Structural redesign and permanent removal of earth fill from the roof slab made it feasible to rehabilitate and strengthen the structure sufficiently to meet seismic criteria that were judged to be compatible with the site conditions. The extensive use of epoxy repair techniques was instrumental in making it possible to salvage large portions of the walls and slabs without complete demolition and replacement.

D-220 Creech, M. F., "Partial-Depth Precast Concrete Patching," Report VHTRC 75-R13, Oct 1974, Virginia Highway and Transportation Research Council.

Experiments were performed with partial-depth precast concrete patching to determine the feasibility of the method. In the experiments, prefabricated slabs of various sizes, stockpiled near the pavement repair site, were installed in machine cut holes in the pavement and cemented into place to make 68 patches. To determine the feasibility of using the cutting machines to prepare deteriorated areas for cast-in-place patches, 22 such patches were installed. Two Klarcrete machines were used to prepare the holes for patching. In the precast patching operations 292.5 sq ft (27.17 m^2) were installed in 88 working hours and in the cast-in-place operations 101.5 sq ft (9.43 m^2) were installed in 26.4 hours.

Major conclusions from the experiments were (1) precast patching is feasible and the machines used to cut the holes did a creditable job, (2) additional projects in the 300-500 sq ft (27.87-46.5 m^2) range are needed to develop a sophisticated methodology for increasing production, and (3) it is desirable to have available a commercial domestic epoxy resin that will cure as rapidly as the imported product.

D-221 Allen, R. T. L., "Repair of Concrete Structures," Publication No. 47.021, 1974, Cement and Concrete Association, London.

Although one of the most valuable characteristics of concrete as a structural material is its durability, sometimes repairs must be carried out. This report gives a general guide to the materials and methods generally used in concrete repair work. Discussed are: repairs to spalled concrete; methods of sealing cracks; gunite (shotcrete); and waterproofing. The report does not deal with repairs to concrete roads or with the removal of superficial stains from concrete.

It is concluded that the essential requirement for success in repair work is thoroughness combined with an understanding of the work involved. If any stage of the work is skimped, the final result is likely to be unsatisfactory. It is desirable for the work to be carried out by experienced operatives working under experienced supervisors who fully understand the reasons behind the techniques that are being used.

D-222 Clear, K. C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair," FHWA-RD-74-5, 1974, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C.

The effect of chloride in reinforced concrete and the chloride content corrosion threshold are discussed. Suggestions for determining the concrete that must be removed prior to permanent repair by utilizing all tools available (delamination detector, electrical potential corrosion detection device, pachometer, and chloride analyses) are discussed. Pulverized samples are rapidly obtained by using a portable hammer, thus eliminating the need to core, section, and pulverize the concrete prior to analysis. Use of the wet chemical analysis procedure for total chloride developed by H. A. Berman is described in detail. Other methods of analysis (neutron activation analysis and various x-ray analyses) in various stages are highlighted.

D-223 Creech, M. F., "Mechanical Alteration of the Texture of Old Concrete Pavement with the Klarcrete Machine," Transportation Research Record No. 484, pp 9-23, 1974, Transportation Research Board.

Experiments were performed with the British Klarcrete machine to determine its capability for removing the top layer of roadway to a depth of 1/8 to 1/4 in. (3.175 to 6.35 mm) and, in so doing, to expose a fresh surface of highly

fractured coarse aggregate to give a better skid resistance. In addition, experimentation was performed to determine whether the machine could be used as an efficient means of completely cleaning bridge decks of coal-tar epoxy prior to resealing. The machine employs 11 percussive hammers, mounted side by side at 2-1/4 in. (57.15 mm) intervals; each strikes the pavement approximately 1500 blows/min and cuts a maximum swath of approximately 4 ft. Each impact removes only a small amount of material but does not injure the surrounding pavement. The sole power requirement is a 600 ft^3 (17 m^3) per min compressor producing 100 lb/in.^{2} (689 kPa) pressure. The machine is self-propelled and its forward speed determines the depth of surface removed.

In the experiments, the machine removed the surface layer of pavement and exposed a new surface of coarse aggregate with fractured jagged edges slightly raised above the surrounding mortar. It left no irrgularities for water to pond and did not impair the riding quality of the road.

1975

D-224 Wilce, B. J., "High Strength Gunite in the Repair of Fire Damage," Concrete (London), Vol 9, No. 3, Mar 1975, pp 28-31.

Provides a detailed description of damage assessment, repair, and restoration of a London warehouse severely damaged by fire. Ultrasonic testing was utilized to reinforce and quantify visual assessments of the fire damage.

Damage to the building, constructed of a steel frame encased in concrete and cast-in-place reinforced concrete floors finished in monolithic grano, ranged from superficial spalling to complete destruction of some reinforcing bars. A newly developed high strength shotcrete with a high percentage of steel was used to complete the repair and restoration of the warehouse.

D-225 Arthanoor, V. A., Srinivasan, D., and Carey, W., "Repairs to a Reinforced Concrete Chimney by the Crack Injection Method," Indian Concrete Journal (Bombay), Vol 49, No. 4, Apr 1975, pp 98-101.

There are four reinforced concrete chimneys built for the Neyveli thermal power-station. Of these, three are 60 m in height, and one 120 m. During the period of a decade or so that they have been in service, the 60 m chimneys have shown signs of excessive strain by developing vertical cracks. Attempts have been made to set these right. The paper describes briefly the pattern of cracks developed, discusses the possible causes of development of the cracks, and the remedial measures carried out.

D-226 "Grinding Rehabilitates Concrete Highway," Civil Engineering (N. Y.), American Society of Civil Engineers, Vol 45, No. 4, Apr 1975, p 12.

The truck lanes of U. S. 101 near Santa Barbara, Calif. were recently rehabilitated by grinding 1/2 in. off the surface leaving a level, corduroy-type surface with an extremely high coefficient of friction. Use of a grinding machine equipped with 265 diamond blades followed by a water truck saved the California Department of Transportation time, money, and inconvenience while extending the life of the highway.

D-227 "Weathering--Cleaning and Restoration of Concrete Structures," Concrete (London), Vol 9, No. 4, Current Practice Sheet No. 22, Apr 1975, pp 43-44.

Factors effecting weathering of concrete can be roughly split into four areas: design considerations; construction practices; position of the structure; and maintenance. Cleaning methods detailed here include water spray; dry grit blasting; wet grit blasting; chemical cleaning; mechanical cleaning; and steam cleaning.

D-228 Chung, H. W., "Epoxy-Repaired Reinforced Concrete Beams," Proceedings, American Concrete Institute, Journal, Vol 72, No. 5, May 1975, pp 233-234.

Tests were carried out on reinforced concrete beams which were severely damaged and then repaired by epoxy injection. The test results illustrate the effectiveness of the repair process.

D-229 Godfrey, K. A., "News in Bridge Decks," <u>Civil Engineering</u> (N. Y.), American Society of Civil Engineers, Vol 45, No. 8, Aug 1975, pp 60-65.

This is the second of two articles on short span bridges. The first, in the July issue, described cost-cutting ideas in design. This article focuses on bridge decks: expansion joints, open steel grid decking, timber decks, the Iowa Method of deck construction (a very low permeability concrete overlay), waterproof membranes, plastic and wax sealing of deck concrete, and various approaches to protecting the rebars from corrosion-galvanizing, epoxy coating, stainless cladding, etc.

D-230 Fairweather, V., "Salt Damaged Bridge Decks: Cathode Protection Helps," <u>Civil Engineering</u> (N. Y.), American Society of Civil Engineers, Vol 45, No. 9, Sep 1975, pp 88-91.

Cathodic protection of bridge decks against spalling caused by deicing salts has been demonstrated effective in decks already damaged. Construction of new decks may use other means to avoid corrosion of steel reinforcing bars by salts; for example, waterproof membranes, or polymer overlays. However, where delamination is severe or where measurements of salts in the pavement indicate imminent spalling, cathodic protection is more economic than replacing the deck.

Potholes are scoured and filled with epoxy first. Then the system is put in place. Silicon iron anodes conduct current through a coke breeze asphalt layer. This current is at a larger voltage than that given off by the corroding reinforcing bar and in the opposite direction. This prevents current from leaving the steel and prevents rust. The method has been used for subsurface pipelines for years, but this application is new. Other methods are considered.

D-231 Thornton, S. I., "Bridge Stains: Causes and Cures," <u>Rural and Urban Roads</u>, Vol 13, No. 9, Sep 1975, pp 36-37.

Stained or discolored bridges look old before their time and give the appearance of being dirty or unkept. Stains may also indicate deterioration of the bridge structure. This article presents some of the information received by

the Arkansas Highway Department in reply to a survey sent to 49 states and the District of Columbia in an effort to solve the problem of staining.

Most reports indicated stain compositions of iron and salt. Rust was the most common stain, and salt from roadway deicing the second most common. Some additional types of stains are briefly listed and preventive measures and treatment of bridges with existing stains are also discussed.

D-232 "Latex Concrete Wearing Surface Placed on Parking Deck," Michigan Contractor and Builder, Vol 69, No. 35, Nov 29, 1975, p 5.

A parking deck in downtown Saginaw, Michigan, received a latex concrete overlay treatment, the same treatment given to bridge decks. Some 110,000 sq ft of concrete was applied to the parking deck. The composition is based on a combination of cement, sand, and/or stone, depending on the application, and modifiers containing styrene butadiene latex or saran latex. These modifiers are film-forming, polymeric emulsions which are designed to upgrade tensile, flexural, and shear bond strengths of paving materials. The modifiers also provide an overlay difficult for water or chlorides to penetrate, and one that resists abrasion and freeze-thaw effects.

D-233 Banov, A., "Proven Organic Coatings for Long-Term Protection," Civil Engineering (N. Y.), American Society of Civil Engineers, Vol 45, No. 12, Dec 1975, pp 45-58.

Recent advances in coating materials and their application make possible improved protection of structures in normal or aggressive environments. Shopcoating and field application are compared. The importance of proper surface preparation, particularly when high performance coatings are used to protect metal in corrosive atmospheres, is stressed.

D-234 Kline, C. A., "Preconstruction Planning, Inspection, and Post Construction Care," Proceedings, American Concrete Institute, Journal, Vol 72, No. 12, Dec 1975.

Pennsylvania Department of Transportation (Penn DOT) procedures are described and compared with the "Recommended Practice for Concrete Highway Bridge Deck Construction (ACI 345-74)" in the categories of preconstruction planning, inspection, and post construction care. The comparison indicated both systems are similar. A detailed comparison indicated that Penn DOT has specifications, policies, and procedures which give quality construciton, but also point out problem areas which are under investigation. The bridge deck deterioration problem has been recognized by Penn DOT. A special bridge deck task force has been established to innovate procedures to obtain improved bridge deck performance. In conjunction, by stressing quality assurance programs, result acceptance plans based on statistical specifications, and contractor-producer quality control programs the durability of bridge decks seems brighter.

D-235 McKeel, W. T., Jr. and Tyson, S. S., "Two-Course Bonded Construction and Overlays," Proceedings, American Concrete Institute, Journal, Vol 72, No. 12, Dec 1975.

Two-course construction has been suggested as an approach to preventing the spalling of concrete bridge decks. Under this procedure the deck is formed and concrete is placed to a level about 0.5 in. (13 mm) above the top mat of reinforcing steel. The first course is levelled with a screed, but no attempt is made to meet normal surface tolerances. When the first course has gained sufficient strength, a second course providing 2 in. (51 mm) of cover over the steel is placed to serve as a riding surface. Great attention can be paid to the quality of the relatively small amount of top course concrete, in both its mix proportions and placement.

The paper presents several advantages inherent in two-course construction, reviews the performance of similar concrete overlays commonly used in the maintenance of existing decks, and suggests materials for use in the important top course.

D-236 "Reinforced Concrete Overlay Upgrades Houston Airport," Proceedings, American Concrete Institute, Journal, Vol 72, No. 12, Dec 1975, pp 665-666.

This paper describes a $10 million upgrading project completed at the Houston Intercontinental Airport in the summer of 1975 which enables the facility to accommodate today's jumbo jets, with plenty of margin for the even larger jets to come.

The basic theme of the upgrading is to prepare runways and taxiways to withstand without distress the ever increasing aircraft load capacities projected. A reinforced portland cement concrete overlay has been selected to accomplish this goal, emulating similar successful improvements at airports in Atlanta, Ga., Cincinnati, Ohio, and Madison, Wis.

The new overlay is called a "mesh dowel" pavement. That is, it is reinforced with welded wire fabric with dowels at the joints transferring loads between slabs. Pavement thickness was based on the design engineer's calculations which took into consideration not only loads and slab panel dimensions, but also the effects of temperature differential existing between the bottom and top of the 18 in. slab.

D-237 Stewart, C. F., "Considerations for Repairing Salt Damaged Bridge Decks," Proceedings, American Concrete Institute, Journal, Vol 72, No. 12, Dec 1975, pp 685-690.

From the wide differences in types, or methods, of salt damaged bridge deck restorations being practiced, it is suspected that a wide difference in philosophy, beliefs, or expected results exist among the practitioners. The short performance history of bridge deck restorations provides little information for the decision makers. Increased communications between researchers should be beneficial in narrowing the philosophy differences and in providing the decision maker with more cost-effective guidance. It is with this in mind that the author discusses factors to be considered when planning a deck restoration. The most important of these factors is the intial cause of the damage and the effect the restoration will have on this cause.

D-238 Byrd, L. G., "Precision Concrete Cutting and Repair System for Pavements," Roadways and Airport Pavements, American Concrete Institute Publication SP-51, 1975, pp 257-267.

Until recently, cutting operations, repairs, and new surfacings on concrete pavements often have necessitated closures for extended periods. A range of equipment and techniques developed in England and recently introduced in the U.S.A. make it possible for the following operations to be carried out during off-peak periods without extended closures to traffic:

1. Repairs to deteriorated or damaged surface areas by the use of partial depth precast concrete slabs or bonded concrete in-situ repairs.

2. Mass-area bush hammering, to remove deteriorated concrete and prepare old concrete surfaces for thin bonded overlays.

3. Bump cutting to correct concrete surface irregularities.

4. Texturing to improve anti-skid characteristics of slippery concrete surfaces.

These processes, which are carried out dry, offer advantages in terms of speed of operation over previous methods. Both the method of cutting concrete and the repair process are approved by airport and highway authorities in the United Kingdom and are being tested in the U.S.A. by the Virginia Highway Research Council.

D-239 Hoff, G. C., "Concept for Rapid Repair of Bomb-Damaged Runways Using Regulated-Set Cement," Technical Report C-75-2, 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

A concept of a system using regulated-set cement for the rapid repair of bomb-damaged runways is presented. Bomb craters formed by the explosion of 750-lb bombs beneath the pavement are repaired by concurrently filling the lower regions of the crater with the ejecta from the crater and a regulated-set cement cellular concrete. As filler nears the top of the crater, the ejecta is omitted and a stronger cellular concrete is placed as the subbase material. A regulated-set cement mortar is placed as the wearing surface. This repair can be applied to make runways operational 4 hr from the start of the repair.

The concept was evaluated by repairing a number of smaller craters using the equipment and procedures developed for the repair concept. The equipment consists of portable continuous batching and pumping equipment. The evaluations indicated

that the equipment possessed sufficient flexibility to repair everything from potholes to full-size craters. The regulated-set cement repair materials could be pumped several hundred feet with this equipment. The repaired surface was level with surrounding pavement surfaces. All regulated-set cement repairs are permanent and do not have to be upgraded or removed and replaced. When used as a subbase material, regulated-set cement cellular concrete can be proportioned to exceed the normal rigid-pavement bearing strength requirements. The early-age flexural strengths of regulated-set cement sanded mortars are adequate for use in rigid pavements. Implementation of the regulated-set cement repair concept reduces manpower requirements approximately 25 percent from that required in present repair procedures. The level of manpower skills required is similar to those presently used. Existing rapid-repair equipment kits would have to be modified for this concept but no new equipment development would be needed. Full-scale crater repairs are recommended for further evaluation of the concept. A sample specification for the continuous batching-pumping equipment is given.

D-240 Jaber, M. M., Fowler, D. W., and Paul, D. R., "Repair of Concrete with Polymers," Research Report No. 114-3, 1975, Center for Highway Research, University of Texas at Austin.

The use of polymers was investigated for repairing cracked or damaged concrete. Several monomer systems, using methyl metacrylate as the primary monomer, were studied. The variables investigated included relative moisture content, crack width, monomer viscosity, concrete temperature, and the use of sand fillers. In many cases the original flexural strength of the plain concrete could be restored by the repair.

The repair of reinforced beams that had been loaded to failure was investigated. Failure modes were flexural and diagonal tension. Sand filler was used with a monomer solution that cured at ambient temperatures. The ratio of repaired beam strength to initial strength ranged from 0.92 to 1.12, with an average of 1.05.

The freeze-thaw durability of repaired nonreinforced slabs was studied to determine the effect of crack width, monomer systems, and surface impregnation and the use of sand fillers. It was found in all cases that the repaired specimens had equal or better freeze-thaw durability than uncracked controls.

Several bridge abutments have been repaired using the techniques developed. A summary of the repairs is given.

D-241 Johansson, L, "Flame Cleaning of Concrete," CBI Report 15:75, 1975, Swedish Cement and Concrete Research Institute, Stockholm.

Flame cleaning of concrete has been investigated in field tests made on large concrete surfaces, as well as in laboratory tests carried out on small concrete slabs which had been prepared specially for this investigation. The tests showed that the thickness of the concrete layer which is removed by cleaning is in part dependent on the speed at which the burner is moved.

Certain definite properties of the concrete surface influence the efficiency of flame cleaning. For instance, a higher moisture content of the concrete increases the rate of concrete removal. In normal cases, when the burner is moved at a speed of about 0.03 m/sec, the thickness of the removed concrete layer is an average of about 1 mm, but can vary from 0.5 to 1.5 mm. At a few individual points, a thickness of up to 4 mm can be obtained.

In comparison with the corresponding concrete that has not been flame-cleaned, the flame-cleaned concrete exhibits about the same bond to epoxy resin adhesives, whereas its bond to cement paste is considerably better.

Flame cleaning can reduce the modulus of rupture of the concrete in the surface layer. No cracks have been detected by visual inspection. Experience has shown that the very fine cracks which might have caused the slight reduction in the modulus of rupture do not give rise to any decrease in the resistance to frost action.

D-242 Knutson, M. J., "Green County, Iowa, Concrete Overlay Research Project," Roadways and Airport Pavements, American Concrete Institute Publication SP-51, 1975, pp 175-195.

The 42 different test sections of the Green County Overlay Project will provide information on the following aspects of concrete pavement overlays: slab thickness, cement content, steel fiber content, joint spacing, bonding characteristics, initial square yard costs, maintenance costs, service

life of different test sections, and comparison of fibrous concrete, continuously reinforced concrete paving with elastic joints, mesh, and plain concrete overlays.

The first objective, to determine the feasibility of batching, mixing, transporting, placing, finishing, and texturing of fibrous concrete with conventional central mix plants and slipform equipment, has been achieved. Although many problems were encountered and solved, further improvements should be made in handling and mixing of fibrous concrete.

It is the feeling of people actively engaged in the construction of this project that given one mix and one design rather than 400-ft test sections, fibrous concrete could be constructed much like common concrete. If the same project were constructed again, using the data obtained, we feel it could be done in half the working time and with 100 percent improvement in ride.

If field practices bear out laboratory conclusions, it appears that industry and the portland cement paving contractors will find a way to make the resulting product or products competitive.

D-243 Kukacka, L. E., Fontana, J., and Steinberg, M., "Polymer-Concrete for Use in the Repair of Deteriorated Bridge Decks," Department of Applied Science, Brookhaven National Laboratory, Upton, New York; Also Transportation Research Record No. 542, pp 20-28, 1975, Transportation Research Board.

One of the most severe problems facing the highway industry is the rapid deterioration of highway-type structures. As part of a concerted effort to solve this problem, research is being performed to determine if concrete-polymer materials can be used for the repair of deteriorated and delaminated bridge decks.

Polymer-concrete (PC) consists of an aggregate mixed with a monomer which is subsequently polymerized in place. It is mixed and placed using techniques similar to those used for portland cement concrete and after curing produces a high-strength, durable material. Process variables studied include monomer-type, aggregate size distribution, and polymerization method.

Field testing of PC has been in progress for 3 yr and to date deterioration has not been observed. One test on a

major arterial highway in New York City has been in progress for 7 months. Based on the success obtained in this experiment and in concurrent laboratory evaluations, further work on the same highway is scheduled for September 1974. These data are summarized.

D-244 Louwerens, W. J. E.,"Flame-Blasting of Concrete," Cement (Amsterdam), No. 6, 1975, pp 259-261.

This new method of concrete finishing consists of searing the outer skin of concrete by means of a high temperature torch 3000° C (5432° F). The surface of the concrete consisting of hydrated cement and sand is pulverized and brushed off, exposing the coarse aggregate.

The article describes the technique and demonstrates that the short exposure of the concrete to such high temperatures does not influence the critical properties of the concrete. The surface finish is economical and attractive.

D-245 "Repair and Maintenance of Concrete," Concrete Manual, 8th ed, Chapter VII, U. S. Bureau of Reclamation, Denver, Colo., 1975, pp 393-438.

Chapter VII covers: (a) General requirements for quality repair - prerepair requirements - use of dry-pack mortar - use of replacement concrete - use of replacement mortar - use of preplaced agg. concrete - use of thermosetting plastic - repairing concrete under unusual conditions - special cases of concrete repair, (b) Maintenance of concrete - protection of concrete against weathering.

D-246 Robinson, D. E., "Successful Electroshock Therapy for Deteriorated Bridges," Transporation Research News, No. 58, pp 3-4, 1975, Transportation Research Board.

A team of research and development employees of the State Highway Commission of Kansas are exploring a new method of removing chlorides from bridge decks in an effort to eliminate

concrete deterioration caused by deicing chemicals. Also included in the project was an attempt to move a polymer into the concrete to fill the voids created by the removal of the chlorides.

The electro-osmosis technique, based on the theory that direct electrical current will pass through concrete, was first tested in the laboratory. The researchers felt that concrete and soils would react similarly, and that the unwanted chloride solution in the bridge decks would act as a conductor of the electricity in the bridge deck.

The top surface of a concrete slab was covered with a copper screen to form a positive electrode. The reinforcing bars in the concrete were used as the negative pole. A direct electrical current was then applied to the electrodes. The negatively charged chloride ion in the water in the concrete block was then attracted to the positive pole. The tests showed the chloride water in the concrete slab was drawn to the surface.

A number of materials were used in the lab to fill the pores, but none proved completely successful. The placement of a material in the pores is an important part of the project to prevent concrete from taking on more chlorides after further deicing applications.

D-247 "Structural Repair of Concrete Cracks by Injection of Epoxy Resin Adhesive," 1975, Training Unit, Research and Development Section, Louisiana Department of Highways.

Until recently, cracks in structural concrete have been a problem with no real solution. Now, by injecting epoxy resin adhesive under pressure into the cracks, structural concrete can be sealed and strengthened. If the original cause of the cracking (strain from shrinkage during curing, overloading, effects of temperature change, or settlement of base or foundations) is corrected, the repaired concrete members can remain strong and resist damage from spalling and from corroding of reinforcing steel. Crack repair can prevent the need for expensive major repair or replacement.

The purpose of this manual is to give practical information on the repair of concrete cracks by epoxy injection to bridge engineers and maintenance personnel of the Louisiana Department of Highways. The manual describes the use and care of the equipment, the preparation of the cracks, and the epoxy injection.

D-248 Weyers, R. E. and Cady, P. D., "Effects of Deicer Salts and Roadway Contaminants on Polymer Impregnation of Bridge Deck Concrete," Transporation Research Record No. 542, pp 41-49, 1975, Transportation Research Board.

Cores, 4 in. (10 cm) wide, extracted from three 7-year-old concrete bridge decks were impregnated with methyl methacrylate to evaluate the effects of deicer salts and roadway contamination on polymer impregnation. All specimens were impregnated by soaking from the top (traffic) surface at atmospheric pressure for a sufficient period of time to achieve approximately 5 in. (12.7 cm) of penetration. Deicer salts, in the quantities measured in the three bridge decks, did not reduce the depth of polymer penetration or the volume of voids filled with polymer. However, the rate of penetration decreased as salt concentration increased. The rate of penetration was a linear function of the square root of time. Removal of roadway contaminants by lye, detergent, or sandblasting had no apparent effect on the rate or extent of polymer impregnation.

1976

D-249 Werse, H. P., "Testing the Resistance of Concrete Bridge Decks to Frost and Deicing Salts," Betonwerk und Fertigteil-Technik (Wiesbaden), Vol 42, No. 1, Jan 1976, pp 24-28; and No. 2, Feb 1976, pp 93-96.

The testing method described is designed to provide a comparative measure of the resistance of various concretes to frost and deicing salts.

D-250 Fisher, J. M., "Repair of Damaged Reinforced Concrete Structures," Concrete (London), Vol 10, No. 3, Mar 1976, pp 26-27.

A recently developed method of repair for the reinstatement of faultily constructed reinforced concrete beams is the use of "prepackaged" unhardened concrete parcels which can be secured to reinforcing bars in the numbers required and heavily compacted into position by simple

hand or mechanical equipment. This method avoids the possible formation of minor cavities in the structure behind reinforcing bars which might arise through their screening of the area from the air/mortar blast, particularly where there is a heavy concentration of steel.

In using this technique the prepackaged wet concrete - not surprisingly dubbed "sausages" - is made up in the amount required by forming cylinders of 23 mm gauge galvanized wire netting up to about 200 mm long and 40 mm diameter, placing them all together into a mold and then completely compacting a suitable grade of concrete therein. When compaction of the concrete within the wire netting sausage skins is complete they can be broken away individually. They are then simply wired onto the exposed and cleaned reinforcing bars ready for compaction against the parent concrete and steel. Sufficient numbers can be used to make up the whole volume of concrete cleared away, leaving just sufficient thickness for the immediate application of a thin rendering built up to the original line of the concrete. While it might be considered advisable to coat the surface of the hard parent concrete and reinforcement with a cement slurry or mortar containing one of the available bonding agents, experience has shown that where the concrete and/or steel have been thoroughly cleaned and all dust has been removed, slight damping with a water spray will be adequate.

D-251 Schrader, E. K. and Munch, A. V., "Deck Slab Repaired by Fibrous Concrete Overlay," Journal of the Construction Division, American Society of Civil Engineers, Vol 102, No. CO1, Mar 1976, pp 179-196.

The concrete deck on the visitors' overlook facility at the Libby Dam became badly cracked and in need of repair. It was decided to overlay the existing surface with 0.75 in. to 2 in. (18 mm to 50 mm) of fibrous concrete. By magnesium floating the surface, excellent grade control and a skid-resistant surface with virtually all fibers covered were obtained.

D-252 Warner, J., "Ventura City Hall Restoration," Journal of the Construction Division, American Society of Civil Engineers, Vol 102, No. CO1, Paper 11970, Mar 1976, pp 119-130.

Describes the modernization of a concrete frame unreinforced masonry filler wall historical structure originally constructed in 1912. Newly developed and novel materials and procedures, including use of a variety of epoxy resin structural adhesives, were utilized in upgrading the structure to conform to all current code requirements including those for seismic loading. The rehabilitation provided for removal and replacement of the heating, air conditioning, plumbing, and electrical systems in their entirety, underpinning and strengthening of the existing floors and walls. In order to preserve the highly decorative irreplaceable exterior surfaces, all strengthening was done from the interior. Included was removal of a portion of the existing masonry and replacement with reinforced gunite followed by injection of an expanding epoxy-ceramic foam structural adhesive into the remaining masonry section resulting in establishment of an absolute bond between the new construction and existing decorative elements.

D-253 Weyers, R. E., Blankenhorn, P. R., Cady, P. D., and Kline, D. E., "Effects of Deicer Salts on the Pressure Impregnation of Bridge Deck Type Concrete with Methyl Methacrylate," Cement and Concrete Research, Vol 6, No. 2, Mar 1976, pp 253-263.

A group of cylindrical concrete specimens containing various known quantities of deicer salts were impregnated from the top surface under a pressure of 75 psig (517 KPa) until complete penetration of the concrete (5 in. or 12.7 cm) was achieved. It was found that increasing salt contents, up to 0.75 percent Cl^- by weight of the mortar fraction of the concrete, had no effect on quantity of monomer absorbed, the volume percent of porosity filled with the monomer, nor on the degree of water absorptivity of the polymer-impregnated concrete. A second group of specimens was impregnated from the top surface at various pressures ranging from 0 to 75 psig (101 to 517 KPa) to a given level of monomer loading. For a given pressure, monomer loading was found to vary directly with the square root of time. Also, it was shown that higher pressures provide denser polymer loadings, higher rates of impregnation, and for a given time period, increased depth of penetration.

D-254 "Diamond Blades Smooth New Concrete Surfaces and Renovate Old Ones," Concrete Construction, Vol 21, No. 4, Apr 1976, pp 167-169.

The necessity for grinding a rough surface on new concrete to make it smooth enough to meet tolerances is no longer bad news. Members of the International Grinding and Grooving Association are routinely smoothing out new pavements. They also use grinding as an alternative to resurfacing when restoring and updating old pavements. Old rough-riding pavements are restored to current smoothness tolerances by grinding with circular diamond-tipped blades. The cost is less than that for resurfacing with new paving materials. Nationwide restoration projects are described.

D-255 Genzlinger, V., "Repairing Old Bridges Can Be Annoying - but Loaded with Lessons," Rural and Urban Roads, Vol 14, No. 5, May 1976, pp 58-59.

Describes repair operations on a 50-year-old two-lane bridge in Minnesota. Deteriorating concrete and exposed reinforcing bars made the repairs necessary, despite earlier patching jobs which included an asphalt overlay. When the job was completed, the engineers working on the job felt that the experience gained by the bridge maintenance unit would definitely contribute toward a marked improvement on any future project.

Holes were cut in the asphalt overlay. Chloride samples taken indicated that the concrete in the center portion was in relatively good condition. When the asphalt overlay was removed, more deterioration was revealed. The majority of the areas fell on the low side of the superelevation.

A chipping unit removed about 1 in. of the old concrete on the deck, plus any pockets of deteriorated concrete below that point. A 1:1 sand cement slurry was used as a bonding agent for the low-slump concrete overlay. The screed available for use was 20 ft wide, but the deck was 26 ft wide, so the crews placed one lane at a time, using a form on centerline. The 4 percent superelevation presented a problem as the power screed tended to slide to the low side because there was no lateral support. The screed operator had to move at an angle to compensate for the superelevation; any future operations on superelevation would not be initiated without a method of lateral support for the power screed. Other problems and their solutions are described.

D-256 Schrader, E. K. and Kaden, R. A., "Outlet Repairs at Dworshak Dam," The Military Engineer, Vol 68, No. 443, May/Jun 1976, pp 254-259.

Sluiceways, spillways, outlets, stilling basins, and similar structures subjected to high-velocity water flows are faced with the serious problem of cavitation forces. As a result, concrete surfaces that carry sustained high-velocity water flows have failed from either erosion or cavitation. The outlets of the Dworshak Dam have suffered such damage and are being repaired using two new concepts in concrete construction, fiber reinforced concrete and polymer impregnated concrete. A fixed-price contract to perform this work was awarded in the spring of 1975. The polymer-impregnated concrete concept is being applied in the field for the first time under such a contract.

Although the regulating outlets at Dworshak Dam have not yet been put back into service, the project appears to be successful. It was shown that it is possible and practical to perform polymer impregnated concrete work and fibrous concrete work under extremely difficult field conditions using a fixed-price contract. Also, it was shown that it is possible to impregnate concrete on vertical surfaces. It appears that polymer impregnation of in-place concrete can be performed in an economical and safe manner under typical construction conditions.

D-257 Schrader, E. K. and Munch, A. V., "Fibrous Concrete Repair of Cavitation Damage," Journal of the Construction Divison, Proceedings, American Society of Civil Engineers, Vol 102, No. CO2, Jun 1976.

Libby Dam is a major high head concrete gravity dam. After moderate usage of the sluices (low level discharge outlets), the one most frequently used developed severe cavitation damage. The sluice was closed and the problem was investigated.

This paper describes the sluice and cavitation damage, analyzes the investigation of the damaged concrete materials, explains the fibrous concrete pour back that was used as a repair, and provides a method for designing a strong workable fibrous concrete mix.

D-258 Pace, C. E., "Engineering Condition Survey and Structural Investigation of Emsworth Locks and Dam, Ohio River," Miscellaneous Paper C-76-8, Aug 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The Concrete Laboratory at the U. S. Army Engineer Waterways Experiment Station was contracted to prepare an engineering condition survey and structural investigation for Locks and Dam 3, Monongahela River, and Emsworth and Montgomery Locks and Dams, Ohio River. This report gives the results of an engineering condition survey and a structural analysis of Emsworth Locks and Dam, Ohio River.

In general, the monoliths on the land wall do not meet present day criteria for overturning, sliding, or base pressures. Also, some monoliths in the middle and river walls do not meet present day stability requirements. In fact, the stability analysis of M-22 along with the visual observation of a 1-1/2-in. separation between the ceiling of the emptying culverts and the middle wall indicates that there has been some movement of these middle wall monoliths.

The main concern for concrete integrity is the cracked, spalled, and deteriorated surface concrete which will allow accelerated deterioration, reducing the effective section of the monoliths and increasing the already excessive tensile stresses. In general, if corrective measures are not taken, this will surely cause maintenance expense and will also reduce the life of the concrete monoliths. The compressive stresses are larger than indicated by the stress analysis and can also cause problems in deteriorated concrete.

From the deteriorated condition of the surface of the lock monoliths, it is evident that some action must be initiated. Since corrective action is needed, a feasibility study should be made to determine what action is necessary to provide the most economical and adequate lock usage over a period of 30 to 50 years. For this reason, it is recommended that a feasibility study be made considering the following alternatives:

a. Minimum maintenance and protection of the locks and dam from weathering with expected replacement when needed as determined by periodic inspections.

b. Rehabilitation of locks and dam.

c. Replacement of locks and dam.

The above recommendations may be affected by a total structural and operational evaluation. In fact, this study

does not evaluate the steel gates, bridge work, lock gates, or appurtenant mechanical or electrical facilities; these will be considered by the Pittsburgh District in the overall evaluation of the locks and dam.

D-259 Pace, C. E., Stowe, R. L, and Buck A. D., "Engineering Condition Survey and Structural Investigation of Locks and Dam 3, Monongahela River," Miscellaneous Paper C-76-9, Aug 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The results of an engineering condition survey and a structural analysis of Locks and Dam 3, Monongahela River, are given.

External cracking of the concrete in the lock walls is extensive. Many horizontal and vertical cracks, although isolated and not fitting into a total failure picture, can result in localized failures, especially in critically stressed regions. The outer 2 to 6 ft of concrete as described in the core and photo logs are highly deteriorated. The same condition probably exists in the outer surface of the walls to lower pool.

The internal concrete is generally of adequate strength for current design criteria. One exception is a small zone in the downstream gate monolith of the middle wall; a compressive strength of 1150 psi was obtained on the concrete from this zone. The concrete is in a critically stressed area; immediate remedial action is recommended. Pressure grouting as an interim measure is suggested. There is one possible continuous crack in gate monolith R-23; it runs for a depth of 35 ft and possibly extends for two-thirds of the monolith to the riverside.

The borehole data indicate a consistent pattern of fractured concrete especially in the lower portions of the monoliths. This can be a significant factor tending to produce problems even at moderatly high stresses.

The foundation appears to be in good condition over most of the lock site. Several local zones of highly fractured rock and one zone where a monolith bears on coal, R-12, are the only zones considered as possible weak rock. During dewatering of the locks, these local foundation conditions could contribute to serious failures of lock wall sections. Such failures could occur due to inadequate sliding resistance of some foundation materials at or near the concrete-foundation contact. There are no detectable continuous

discontinuities, zones of fracture, or seams of weak materia[l.] bedding planes are the only detectable continuous features over the lock site.

The stability analysis reflects deficiencies in many are[as:]

a. In general the monoliths in the land wall do not com[-]ply with current criteria for overturning, sliding, or allow[-]able base pressures.

b. Some middle wall monoliths do not have adequate resistance to sliding.

c. Some monoliths in the river wall do not have adequate resistance to sliding, and where coal seams underlie monolith[s] critical situations can exist if the river lock is ever de-watered. Bearing pressures are excessive in the upper guard wall causing it to tilt riverward.

The stability analysis for the land wall monoliths shows severe inadequacies and as with the guard wall and the abut-ment, it is probable that stability problems will develop. These problems can cause considerable delays to navigation through these locks.

The upper guard wall has excessive bearing pressures be-tween the upper and lower timber cribbing sections and has tilted riverward. There are probably some rocks between the cribbing members which result in more bearing area and, there-fore, reduce the calculated stresses considerably. However, the tilting of the guard wall shows that the bearing pres-sures are still excessive.

discontinuities, zones of fracture, or seams of weak material; bedding planes are the only detectable continuous features over the lock site.

The stability analysis reflects deficiencies in many areas:

a. In general the monoliths in the land wall do not comply with current criteria for overturning, sliding, or allowable base pressures.

b. Some middle wall monoliths do not have adequate resistance to sliding.

c. Some monoliths in the river wall do not have adequate resistance to sliding, and where coal seams underlie monoliths critical situations can exist if the river lock is ever dewatered. Bearing pressures are excessive in the upper guard wall causing it to tilt riverward.

The stability analysis for the land wall monoliths shows severe inadequacies and as with the guard wall and the abutment, it is probable that stability problems will develop. These problems can cause considerable delays to navigation through these locks.

The upper guard wall has excessive bearing pressures between the upper and lower timber cribbing sections and has tilted riverward. There are probably some rocks between the cribbing members which result in more bearing area and, therefore, reduce the calculated stresses considerably. However, the tilting of the guard wall shows that the bearing pressures are still excessive. Tow impact can cause this guard wall to fail.

D-260 Slater, J. E., Lankard, D. R., and Moreland, P. J., "Electrochemical Removal of Chlorides from Concrete Bridge Decks," Materials Performance, Vol 15, No. 11, Nov 1976, pp 21-26.

Deterioration of portland cement concrete bridge decks is a serious problem in many parts of the United States, resulting in high maintenance costs to keep the decks in safe and serviceable condition. Although deck deterioration can take several forms, the spalling problem has become the major cause of maintenance. The increased frequency of spalling appears to be directly related to the increased use of deicing salts (primarily $CaCl_2$ and NaCl) in recent years. Chloride ions accelerate the rate of corrosion of the reinforcing steel in the concrete. The formation of corrosion products on the steel results in a buildup of stresses in the concrete which is ultimately manifested as spalling of concrete on the deck surface.

A number of potential solutions to the problem are being researched. This article discusses the actual removal of the chloride from the concrete by electrochemical means. Results of laboratory and on-site tests are discussed. It is concluded that the techique is technically feasible, and results of core evaluations and potential tests indicate that reinforcing bars stopped corroding after the electrochemical treatment.

D-261 "Damp Proofing: Note 1 - Water Vapour," New Zealand Concrete Construction (Wellington), Vol 20, No. 10, Dec 1976, pp 27-28.

A series of four notes followed by a summary is being published on the subject of dampproofing. This first note includes a brief discussion of moisture migration and the importance of vapor barriers and ventilation in maintaining concrete durability. Note 2 will cover the influence of ground condition. Note 3 will cover water surface contact. Note 4 will be on water pressure.

D-262 "Injection of Special Heat-Resistant Epoxy Halts Cracking of Boiler Pads," Construction Adhesives, Coatings, and Sealants, Adhesive Engineering Co., St. Carlos, Calif., Vol XI, No. 3, Dec 1976, p 6.

Describes how cracks in the concrete pads supporting four huge boilers have been successfully repaired by injection with a special high temperature resistant epoxy adhesive.

D-263 "Pier Restoration at the Port of Albany Nears Completion," Constructioneer, South Edition, 6 Dec 1976, pp 28-30.

The first phase of an extensive improvement program at the Port of Albany, restoration of a major pier and shed on the Hudson River, is nearing completion. The $2.5 million project called for reconstructing a partially collapsed pier and installing a new concrete floor, new doors, new siding, and roofing on the shed. The new concrete pier is 40-1/2 ft wide and 500 ft long.

D-264 "SCB Crack Injection Repairs Ribbed Concrete Walls Without Marring," Construction Adhesives, Coatings, and Sealants, Adhesive Engineering Co., St. Carlos, Calif., Vol XI, No. 3, Dec 1976, p 3.

Over 5000 lin ft of hairline cracking in the exterior shearwalls and roof parapets of a 500 bed Veterans Administration hospital in Loma Linda, Calif., were repaired by the structural concrete bonding process not only to fill the cracks as a means of waterproofing but also to preserve the building's architectural ribbed concrete surfaces.

The structural concrete bonding process was selected for repairs because (1) it was a sure method to fill the hairline cracks full depth; and (2) the high bond strength of the epoxy adhesive will prevent cracks from reopening during the severe thermal changes that occur in the area, known for relatively high and low temperatures. The structural concrete bonding process has also proven itself on past jobs requiring complete preservation of architectural esthetics. It also eliminates the efflorescence buildup and staining that normally occurs because of water action in cracked concrete.

Sample cores taken along an exterior wall selected by resident engineers showed more than 95 percent penetration of the epoxy.

D-265 Fisher, J. E. and Welsh, J. P., "South Bend Dam Repaired," Foundation Facts, Vol 11, No. 1, 1976, pp 22-25.

An investigation of the 120-year-old dam on the St. Joseph River in South Bend, Ind., indicated serious deterioration of the concrete cap and the existance of voids and solution channels in the rock-filled base below the concrete cap. The structural stability of the weir-type dam was restored by pressure grouting, installation of a new toewall, and resurfacing of the concrete.

D-266 Mustard, J. N., "Repairs to Concrete Structures," Proceedings, Third Symposium on Modern Concrete Technology (Caracas, Nov 1976), Associacion Venezolana de Productores de Cementos/American Concrete Institute, 1976.

Extensive repair of critical concrete structures has to be carefully appraised to determine the circumstances which necessitated the repair. After establishing the reason for the deterioration and its extent, the most important consideration is how the proposed repair material will act with the parent concrete under the expected conditions.

This paper discusses methods and materials for repairing damage to exposed horizontal surfaces, dam sluiceways, and columns under load. Six case studies of repairs carried out with various materials with observations of limited laboratory investigations are described.

D-267 Van Til, C. J., Carr, B. J., and Vallerga, B. A., "Waterproof Membranes for Protection of Concrete Bridge Decks - Laboratory Phase," NCHRP Report No. 165, 1976, Transportation Research Board, Washington, D.C.

This report is recommended to bridge design engineers, construction engineers, materials engineers, maintenance engineers, research engineers, and others concerned with the preservation of concrete bridge decks. It describes the findings of a comprehensive assessment of the protective capabilities of all bridge deck waterproofing membrane systems available when the project started. This report presents the results of laboratory research carried out in the first phase to define the service requirements and the significant properties of membrane waterproofing systems and to devise an experimental program for evaluating the performance of the membrane systems under investigation. The second phase included field evaluation of the selected membrane systems.

In this report, 147 known membrane systems were subjected to preliminary examination. Twenty-five systems in place on existing bridge decks were inspected during the preliminary examination. Seventy-eight of the initial 147 systems showed sufficient promise to be selected for more detailed study. A comprehensive series of laboratory characterization and performance tests produced nine candidates for a field application test. Permeability, crack-bridging capability, durability, resistance to impact damage, and structural serviceability were among the principal characteristics examined in the laboratory. Ease of application was tested in the field. As a result of the testing, five systems were selected as the most promising for further evaluation in the in-service environment. The surviving membranes consisted of vulcanized, cured, or crosslinked elastomers, all of which appeared to

provide good dimensional stability on exposure to asphaltic concrete placed at normal application temperature, to water, to solar heat, and to freeze-thaw conditions.

<u>1977</u>

D-268 Liu, T. C., "Engineering Condition Survey and Structural Investigation of Marsh Arch Bridge, Fort Riley, Kansas," Miscellaneous Paper C-77-1, Jan 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report presents the results of an engineering condition survey and structural investigation of Marsh Arch Bridge over the Republican River at the west side of Fort Riley, Kansas.

A visual inspection of the bridge with special attention given to concrete cracking, spalling, and deterioration was performed. Fourteen concrete core samples were taken and laboratory tests were performed to determine the cause and extent of deterioration and to obtain mechanical properties necessary for stress analyses. Detailed stress analyses were performed to determine the stress conditions in the bridge.

Based on the results of this investigation, it can be concluded that the bridge is in an advanced state of deterioration and any practical repairs will not be economically feasible.

Although the bridge is still considered to be structurally adequate for the present traffic conditions (i.e., one-lane traffic with 10-ton load limit), catastrophic failure could occur in the not too distant future because the rate of the deterioration will be accelerated due to the existence of large concrete cracks and the exposure of the steel elements.

It is, therefore, recommended that an early action toward replacement of this bridge (both super- and substructures) be initiated.

D-269 "Bridge Stays Open During Replacement," <u>Engineering News-Record</u>, Vol 198, No. 5, Feb 3, 1977, p 18.

A Colorado contractor recently converted a two-lane steel truss Texas bridge into a four-lane prestressed concrete girder structure without ever shutting off traffic completely. The state required at least one lane be kept open for emergency traffic during the entire job.

The contractor did the job in three states. First, he constructed a new prestressed concrete girder crossing, from foundation up, on either side of the old bridge. Then he cut out the middle lanes and placed new girders and superstructure. And finally he dismantled the 40-year-old trusses.

D-270 "Four Concrete Overlay Methods Tested for Street Resurfacing," Modern Concrete, Vol 40, No. 10, Feb 1977, pp 52-54 and 57.

In an effort to find a low cost, long-lasting surface for existing streets, the city of Anderson, Indiana, has built a test section comparing several types of resurfacing using ready-mixed concrete.

The test pavement section is 200 ft long. Four different 100 ft sections have been resurfaced, each 25 ft wide, or half the width of the existing section.

The four different test sections are: 4 in. of concrete over polyethylene film; 4 in. of concrete placed directly on old pavement that has been broken up; 3 in. of concrete over old pavement using wire mesh; and 4 in. of concrete over old pavement using impregnated paper strips to isolate existing cracks.

D-271 "Guide to Repair of Concrete," Concrete Construction, Vol 22, No. 3, Mar 1977, pp 123-178.

In a question-and-answer format, this issue is devoted to the repair of concrete. The 101 problems have been classified into 19 repair techniques. The answers reflect the latest practices and standards. A reference list for additional information concludes the issue.

The 19 techniques covered are: acid etching and washing; bonding; cleaning, removing stains, and discoloration; crack and joint repairing; evaluating damage; grooving and grinding; grouting; leveling; liquid floor hardening; overlaying; painting, coating, and lining; patching; plastering;

resurfacing; sawing, drilling, and cutting; shotcreting; slabjacking; underwater repairing; and waterproofing.

D-272 Pace, C. E. and Peatross, J. T., Jr., "Engineering Condition Survey and Structural Investigation of Montgomery Locks and Dam, Ohio River," Miscellaneous Paper C-77-2, Mar 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

The Concrete Laboratory at the U. S. Army Engineer Waterways Experiment Station was contracted to prepare an engineering condition survey and structural investigation for Locks and Dam 3, Monongahela River, and Emsworth and Montgomery Locks and Dams, Ohio River. This report gives the results of an engineering condition survey and a structural analysis of Montgomery Locks and Dams, Ohio River.

There is general spalling, leaching, and cracking of the concrete surfaces of Montgomery Locks and Dam. The crack survey implies that a majority of the cracking in the lock walls is caused by barge impact. The longitudinal crack parallel to the lock in the middle wall of Montgomery Lock is hypothesized to be caused by barge impact; therefore, this can be a source of deterioration which increases with lock use. The soniscope study indicates that the cracking along the center of the middle wall does not worsen with depth. The concern of the cracks and spalled areas in the concrete surface is that they will allow the access of water, thereby causing an increased rate of deterioration due to freezing and thawing. Maintenance of the surface cracks and spalled areas is, therefore, essential.

In relation to present-day criteria, almost all of the monoliths on the land wall are inadequate in their resistance to overturning and base pressures. In general, the monoliths in middle and river walls are inadequate in their resistance to overturning. This is especially true for the middle wall monoliths in the dewatered case. The miter sills are inadequate for sliding if the locks are dewatered.

The stress in the culvert wall of monolith M-8 is greater than 800 psi tension. This tensile stress is too large and will crack the concrete. This allows a stress flow up through the center of the monoliths, thereby causing cracking. This hypothesized condition for cracking should be checked by inspecting the culvert walls as soon as possible.

Cracking and deterioration of the exposed concrete are severe problems and are significant at stress concentrations.

Stress analysis shows that gouges and concrete deterioration can become problems in the upper guide wall. Excessive stress concentrations exist in the structural slab over the filling and emptying flume. Tensile stresses indicate magnitudes that are excessive for even good quality concrete. Compressive stresses indicate magnitudes that would not be considered excessive for sound, uncracked concrete; however, for badly deteriorated concrete, they are excessive. Stress concentrations also exist at gate anchorages. As the concrete at Locks and Dam 3 continues to deteriorate, stress magnitudes under existing loading conditions, as has been observed, will become a problem.

The locks have apparently functioned well for over 70 years, but this cannot be expected to continue indefinitely because of accelerating deterioration due to concrete cracking, leaching, and exposure to a freezing-and-thawing environment. These locks and dam will have to be replaced or rehabilitated.

It is recommended that a study be initiated immediately to evaluate rehabilitation or replacement of Locks and Dam 3 on the Monongahela River.

D-273 Graham, J. R. and Rutenbeck, T. E., "Repair of Cavitation Damaged Concrete," Paper presented at International Conference on Wear of Materials, St. Louis, Mo., Apr 1977.

The Bureau of Reclamation has been faced with the phenomenon of cavitation and its detrimental effects on concrete in water control and conveyance structures for over 50 years. One might expect in that period of time that effective methods of mitigating cavitation damage and effectively protecting concrete would have been developed. Many systems and techniques designed to solve the cavitation problem have been attempted through the years with only marginal success. New design approaches have been used, improved materials of construction tested, better specifications prepared, and whenever possible, better construction practices have been used. This paper briefly discusses some Bureau of Reclamation techniques and experiences regarding repair of cavitation damaged concrete. A few case histories describing actual structural rehabilitation are presented as well as some specific information on repair procedures using epoxy materials.

D-274 Slater, J. E. and Lankard, D. R., "Effect of Bridge Deck Repairs on Corrosion of Reinforcing Steel," Rural and Urban Roads, Vol 15, No. 5, May 1977.

Article describes procedures used to evaluate rate of corrosion to steel under various types of repair patches. The materials include polymer cement concrete, epoxy concrete, repairs with overlays and fast-setting repair materials.

D-275 McDonald, J. E. and Campbell, R. L., "An Investigation of Concrete Condition, William Bacon Oliver Lock and Spillway," Miscellaneous Paper C-77-5, Jun 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report presents the results of an investigation to assess the condition of the concrete in William Bacon Oliver Lock and Spillway on the Warrior-Tombigbee Waterway near Tuscaloosa, AL. The investigation included (1) crack survey of lock walls, (2) soniscope investigation of lock and spillway, (3) examination and tests of concrete and foundation cores to determine material properties, (4) stress analysis of the upper land wall gate monolith.

Results indicate the concrete, despite extensive cracking in some monoliths containing the higher-alkali cement, is of generally good quality. Although the concrete still has the potential for internal growth and expansion due to alkali-silica reaction, any increases in cracking in recent years is more likely attributed to physical deterioration, such as freezing and thawing, than to the direct effects of continued alkali-silica reaction.

In situ pulse velocity data obtained during the period 1948-1976 indicate that, of the monoliths tested, only the concrete in Monolith Nos. 16 and 20 would be classified as questionable. However, the same data indicate that the concrete in these monoliths is not experiencing progressive deterioration; in fact, the trend is for increased pulse velocities since tests were initiated. Similarly, a comparison between current surface cracking and monolith displacements and that present in 1948 indicates that present conditions are not significantly different from those found at the time of the initial investigation.

Results of the material property tests indicate the current concrete quality to be generally good and substantially unchanged from the initial investigation in 1948. This tends to alleviate the concern regarding the effect of reduced concrete strengths on the magnitude and location of stress concentrations within gate monoliths.

Extensive repairs and/or rehabilitation of the structure do not appear necessary at present. For specific areas identified through continuing periodic inspections as requiring maintenance, removal of approximately 1-3 ft of surface concrete and replacement with new concrete is recommended.

D-276 Pace, C. E., "Engineering Condition Survey of Troy Lock and Dam," in preparation, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

This report presents the results of Phase I work which consists of a condition survey of Troy Lock and Dam. The analysis of the condition survey as given in this report gives adequate information for good engineering decisions needed for developing a proposal for the total evaluation of the Lock and Dam which is to be accomplished in the Phase II work.

Initial observations of Troy Lock and Dam give worse impressions of structural deficiencies than are actually the case. The Phase I study reveals that the interior concrete of the lock is sound and of sufficient strength. The concrete cracking of the lock is negligible and is insignificant in the dam and gated spillway except for:

a. The pier where the access to the dam tunnel on the powerhouse side of the river is located.

b. The piers of the gated section.

Undated

D-277 Cartensen, J. R. and Nabors, W. M., "Fast Fix Pavement Repair," Military Engineer, Vol 61, No. 403, pp 352-353.

For a number of years, the Air Force has sought improved methods and materials for rapid repair of airfield pavements damaged by enemy fire. The basic techiques used have not

been altogether satisfactory. Laboratory and field tests have been made of several organic and inorganic materials including polyester resins, vinylester resins, and gypsum cements combined with a small quantity of portland cement. A rating system, based upon such factors as cost, strength, set time, curing time, and simplicity of application equipment, was used in the selection of the best material for which the system could be developed. The material selected is called Fast Fix. Three blends were developed. Fast Fix 1 has been used most often in field tests. It consists, by weight, of 95 percent gypsum hydrostone cement and 5 percent Type 1 portland cement, to which is added a small quantity of TF-4, a wetting agent, to produce a high-slump mixture at a low water-cement ratio. Fast Fix 1 gels 7 minutes after water is added; it sets in 12 minutes, and may be loaded at age 30 minutes. Fast Fix 2 and Fast Fix 3 are mixtures of other gypsum cements and different quantities of portland cement. Set time can be extended with several retarding agents among which are WR-1 (a proprietary product), sodium citrate, and sugar. Sugar is recommended only to retard the set permanently or "kill" the mix.

D-278 Crump, L. W. and Bone, A. J., "Condition Surveys of Bituminous Resurfacings Over Concrete Pavements," Massachusetts Institute of Technology.

This paper describes a technique for making and analyzing condition surveys of bituminous resurfacings over concrete pavements. Successive surveys provide a basis for evaluating the performance of different resurfacing types.

Survey sections include about 1000 ft of typical pavement. The location and extent of all defects are measured in the field and recorded directly on forms prepared for that purpose. All cracks are classified by width and by their most likely cause, which can usually be determined quite accurately by observation or by inspection of construction and maintenance records.

Indices are computed from the field data, and are used to compare the performance of the different resurfacings. They are computed for the incidence of cracking over transverse and longitudinal joints, over joints between concrete and adjacent bituminous shoulders, at construction joints in the resurfacing, and over cracks and other defects in the underlying concrete.

AD-A062 694 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 5/2
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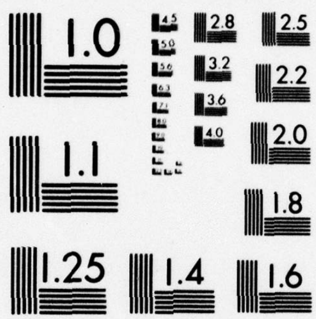

The survey method differs from those applicable to concrete pavements or to bituminous surfaces on flexible bases. Defects may be caused by deterioration of either the concrete or the bituminous resurfacing, or by the dissimilar properties of the two materials. The method has been developed and refined through two years of data collecting, and has been successfully used on repeated surveys of 25 test sections totaling over 6 miles in length.

D-279 Felt, E. J., "Resurfacing and Patching Concrete Pavements with Bonded Concrete," Portland Cement Association.

Resurfacing or patching of old concrete pavements with bonded concrete has been extensively studied and found to be feasible. Many factors are involved in developing the good bond between new and old concrete essential for thin resurfacing and patching.

This report covers laboratory bond tests, experimental field projects, a survey of projects in use, and recommended practices. Laboratory data and field work indicate that bond strengths as determined by a shear test can frequently be 400 psi or more, but that strengths of 200 psi or even less may be adequte. The two main factors governing bond are: (1) the strength and integrity of the old base concrete, and (2) the cleanness of the old surface. Mechanical cleaning was found to be essential if a weak surface layer is present, whereas cleaning of sound concrete can be accomplished with hydrochloric (muriatic) acid. Good compaction of the fresh concrete is also required for a strong bond. Other factors of importance include the precise placement of new joints over old ones and adequate curing of the fresh concrete.

The performance of experimental projects and other projects in service shows that properly bonded surfaces will withstand extreme climatic conditions and heavy traffic. Thin bonded resurfaces giving satisfactory service date back to 1913.

Recommended practices are given in the last section of the paper. They specify in detail techniques which have been proved to be best for successfully bonding new and old concrete. The need for good workmanship and suitable materials, essential in applying the recommended practices, cannot be overemphasized.

D-280 Florence, R. L. and Southgate, H. F., "Slurry Seal Maintenance Applications," Bureau of Public Roads (US) HPR-1 (5), No. 6, State No. 64-7, Kentucky Department of Highways.

A field evaluation was made of sand-emulsion slurry seals on roadways in Kentucky. Slurry seals were studied as they presented an opportunity to utilize hard sands for skid resistance, and to avoid loose surpluses of stone chips associated with conventional seal coats. This report documents the development and performance of slurry seals in Kentucky. The principal conclusions of this research are: (1) slurry seals were not effective in sealing cracks; reflection cracks were noted in relatively short periods of time, (2) a maximum life of about three years was found for the heaviest applications, (3) the skid resistance of a surface can be improved by use of these seals; however, where an excess of asphalt is the initial problem, improvement is minimal, and (4) the material requires a long curing time and is particularly sensitive to aggregate.

D-281 Hughes, R. D. and Scoff, J. W., "Concrete Bridge Decks: Deterioration and Repair, Protective Coatings, and Admixtures," PB 173 364, Clearing House for Federal Scientific and Technical Information.

From observations on a large number of concrete bridge decks in Kentucky and measures used for protection and repair, the authors make a number of recommendations to improve deck durability.

A minimum of 2 in. of concrete should be provided above the top layer of reinforcement. Reinforcing steel should be carefully inspected for rigidity and elevation. It is recommended that full-width screeding and floating machines, controlled by precise crown and grade templates, be required on all concrete-deck construction. The deck-finishing machine should be passed over the deck prior to placement of concrete in order that the clearances from the bottom of the screed to the top of steel may be measured.

Concreting should not commence until it has been definitely established that sufficient equipment is to be employed for the rapid delivery and placement of concrete. Concrete should be deposited immediately in front of the screed, and an excess should be maintained at that location. Slump and air-content tests should be performed on samples obtained from each batch,

and time of mixing should be noted. Regardless of circumstances, all batches that do not meet specification requirements for slump, air-content, and time of mixing should be rejected.

Every effort should be made to prevent workmen from walking in or on fresh concrete. Low areas should be overfilled slightly with fresh concrete and rescreeded rather than pulling in soupy mortar from surrounding areas. Excessive vibration and overfinishing should be discouraged, and the addition of water to the surface during finishing (tempering) should be prohibited.

Curing covers or membranes should be placed immediately after finishing. Curing compounds should not be applied until the sheen of bleed water has disappeared nor should the application be delayed beyond this time.

Cleaning and rinsing of decks, particularly after heavy applications of deicing chemicals and sand or cinders, should be a standard practice. Boiled linseed oil should be applied at 2 to 4-year intervals. Periodic inspections should be made in order to detect deterioration and to effect repairs.

In making repairs, all unsound concrete should be removed, and the perimeter of such areas should be sawed in order to eliminate "feather-edging." Air-entrained concrete is recommended for use in patching depths of 2 in. or greater. Sufficient bond is insured by thoroughly wetting the surfaces, removing excess water, and then coating the surfaces with a thick paste of cement and water immediately before filling with fresh concrete. The maximum size of coarse aggregate should not be greater than one-half the depth of area to be patched. High-early-strength cement or an accelerator should be used for patching in congested areas. Latex-modified or epoxy-resin mortars should be employed in shallow patches. Again, bonding is insured by painting all surfaces with a thick paste of latex-modified cement and water or epoxy resin. In the event bituminous concrete is to be used in patches or as an overlay, the use of a bituminous bonding coat is equally important.

D-282 Rooney, H. A. and Botts, E. W., "Epoxy Adhesives as Structural Repair Material," California Highways and Public Works, pp 48-50.

Epoxy adhesives used to bond old concrete to old concrete and new concrete to old concrete have been successfully tested in the laboratory. Field applications of this adhesive was tried in 1954 on the Yolo County Causeway. A cracked section

of the roadway was removed and adhesive was applied to the edges of the break in the slab immediately before fresh concrete was placed in the patch. One year later the patch was examined and no signs of cracking or other failures were visible. Similar results were obtained on the Marina Viaduct in San Francisco.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Liu, Tony C

Maintenance and preservation of concrete structures; Report 1: Annotated bibliography, 1927-1977 / by Tony C. Liu, Edward F. O'Neil, James E. McDonald. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

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